The business and technology of the Sheffield Armaments industry 1900-1930

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The Business and Technology of the Sheffield Armaments Industry 1900-1930

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Abstract

This exploration of the Sheffield armaments industry focuses on four in-depth case studies of John Brown, Cammell-Laird, Thomas Firth and Hadfields to examine the business and technology of the industry. It builds on the work of Tweedale and Trebilcock on Sheffield and armaments, and advances the argument that during the period of study from 1900 to 1930, the city was one of the most important centres for armaments research and production anywhere in the world.

The business of the armaments industry is explored through an examination of the evolving links the industry had with the Government against the backdrop of an uncertain trading environment, and the managerial connections established between the state and private industry. Also explored are the collaborative, collusive and independent defensive measures enacted by the industry to counter uncertainty in the industry, through collaborative business arrangements and various approaches to entering international markets for armaments. An examination of the business of the armaments industry also highlights the value of the technological investment made by the industry.

At the centre of exploring the technology of the armaments industry, a reconstruction of its technological history is undertaken using patent and archival records, highlighting the nuances and research dead-ends of development in the industry. Of central importance is the notion of spin-off and the interactions between armaments and metallurgical developments in the creation of a pool of knowledge to be utilised for future research into alloy steels, and the notion of path-dependent technological research. Also advanced is the concept of an innovation system centred on Sheffield, and an exploration of the important national and international links advanced by the industry.

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Candidates Statement

The objectives of this research were as follows. Using four case studies, the research set out to examine the technological development of armaments, the industrial district in which the Sheffield armaments industry was situated, the marketing involved and the connections developed to home and foreign governments by members of the industry, and the specialised management required for armaments research, production, and marketing, across the period 1900-1930. To achieve this, the archival business records and patents of the case studies were consulted. Published sources have been referenced throughout with footnote citations and are included in the bibliography in full.

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Introduction

This study explores the business and technology of the Sheffield armaments industry through the examination of four company case studies in John Brown, Thomas Firth, Charles Cammell and Hadfields. Using a thematic approach, the research will explore the technological development of armaments, the industrial district in which the Sheffield armaments industry was situated, the marketing involved and the connections developed to home and foreign governments by members of the industry, and the specialised management required for armaments research, production, and marketing. Commencing in 1900, when large numbers of orders were placed with private industry due to the Boer War, this study examines the three decades through to 1930, when steel rationalisation programmes changed the structure of the industry. The research builds principally on the work of Trebilcock on the armaments industry, and the work of Tweedale on the Sheffield steel industry.[1] By utilising the case studies outlined, new source material, and reconstructing the technological history of the industry from the use of published patent records, a number of refinements and revisions can be made to key aspects of knowledge regarding the Sheffield armaments industry. In his seminal work on the Sheffield steel industry, Tweedale highlights that:

> The subject of the Sheffield armaments industry – the significance of which may be appreciated by the simple fact that all but one (Armstrong-Whitworth) of the traditional arms firms originated in the town – demands

[1] See R.C, Trebilcock, 'A 'Special Relationship' – Government, Rearmament, and the Cordite Firms', *Economic History Review*, Vol.19, No.2 (1966); C. Trebilcock, '"Spin-Off" in British Economic History: Armaments and Industry, 1760-1914', *Economic History Review*, Vol. 22, No. 3 (1969), pp.474-90; C. Trebilcock, 'Legends of the British Armament Industry 1890-1914: A Revision, *Journal of Contemporary History*, Vol.5, No.4 (1970), pp.3-19; C. Trebilcock, 'British Armaments and European Industrialization, 1890-1914', *Economic History Review,* Vol.26, No.2. (1973), p.254-272; C. Trebilcock, 'Radicalism and the Armament Trust', *Edwardian Radicalism 1900-1914* (London, Routledge and Kegan Paul, 1974), pp.180-201; C. Trebilcock, 'War and the failure of industrial mobilization: 1899 and 1914' in J.M. Winter, *War and Economic Development, Essays in the memory of David Joslin* (Cambridge, Cambridge University Press, 1975); C. Trebilcock, *The Vickers Brothers: Armaments and Enterprise 1854-1914* (London, Europa Publications, 1977); C. Trebilcock, 'Science, Technology and the Armaments Industry in the UK and Europe, with special reference to the Period 1880-1914', *The Journal of European Economic History*, Vol.22, No.3 (1993); and G. Tweedale, *Steel City: Entrepreneurship, Strategy and Technology in Sheffield 1743-1993* (Oxford, Clarendon Press, 1995), especially Chapter 5: Arsenal of the World.

a whole book in itself. Certainly it deserves closer attention than it has received in most studies about the industry.[2]

Tweedale also highlights the work of Trebilcock and Davenport-Hines on the Sheffield armaments industry, principally in relation to Vickers, and for taking a critical approach to the subject.[3] Nevertheless, a work on the Sheffield armaments industry is still absent among studies of British business history, a historiographical gap which this thesis will readdress.[4]

While a number of studies have been conducted on the armaments industry in Britain, there are some limitations which can be highlighted. Firstly, there has been a trend to examine the period prior to 1914, and from 1918 to 1939 as two distinct periods in the history of the armaments industry, with business actions in the Great War overlooked and discussions of continuity and change in the industry across a longer period not fully examined.[5] Secondly,

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[2] Tweedale, *Steel City*, p.71.

[3] Tweedale is specifically referring to Trebilcock, *Vickers Brothers* and R.P.T. Davenport-Hines, *Dudley Docker: The Life and Times of a Trade Warrior* (Cambridge, Cambridge University Press, 1984), Chapter 8: Armaments, Electricity and Rolling Stock. See also R.P.T. Davenport-Hines, *The British Armaments Industry during Disarmament* (Unpublished Thesis, University of Cambridge, 1979); R.P.T. Davenport-Hines, 'Vickers Balkan Conscience: Aspects of Anglo-Romanian Armaments 1918-39', in R.P.T. Davenport-Hines (Eds.), *Business in the Age of Depression and War* (London, Frank Cass, 1990), pp.253-285; R.P.T. Davenport-Hines, 'The British Marketing of Armaments 1885-1935' in R.P.T. Davenport-Hines, *Markets and Bagmen: Studies in the History of Marketing and British Industrial Performance 1830-1939* (Aldershot, Gower Publishing, 1986); R.P.T. Davenport-Hines, 'Vickers as a Multinational Before 1945', in G. Jones, *British Multinationals: Origins, Management and Performance* (Aldershot, Gower Publishing, 1986).

[4] There is one local history book which has been produced, with little new information or analytical value. See S. Dalton, *Sheffield: Armourer to the British Empire* (Barnsley, Wharncliffe Books, 2004).

[5] The key examples of this are Trebilcock, Spin-Off; Trebilcock, *Vickers Brothers*; Davenport-Hines, *The British Armaments Industry during Disarmament*; Davenport-Hines, Vickers Balkan Conscience; G.A.H. Gordon, *British Seapower and Procurement between the Wars: A Reappraisal of Rearmament* (Annapolis, Naval Institute Press, 1988); A. Slaven, 'A Shipyard in Depression: John Browns of Clydebank 1919-1938' in R.P.T. Davenport-Hines (Eds.), *Business in the Age of Depression and War* (London, Frank Cass, 1990); J. Singleton, 'Full Steam Ahead? The British Arms Industry and the Market for Warships, 1850-1914' in J. Brown and M.B. Rose, *Entrepreneurship, Networks and Modern Business* (Manchester, Manchester University Press, 1993); E.F. Packard, *Whitehall, Industrial Mobilisation and the Private Manufacture of Armaments: British State-Industry Relations, 1918-1936* (London School of Economics, Unpublished PhD Thesis, 2009); R. Lloyd-Jones, and M.J. Lewis, 'Armaments Firms, The State Procurement System, and the Naval Industrial Complex in Edwardian Britain', *Essays in Economic and Business History,* Vol.29, No.1 (2011), pp.23-39; G. Marchisio, *Battleships and Dividends: The Rise of Private Armaments Firms in Great Britain and Italy c.1860-1914*, (Durham University, Unpublished PhD Thesis, 2012). There are also some exceptions, including D. Edgerton, 'Public Ownership in the British Arms Industry, 1920-1950' in R. Millward and J. Singleton, *The Political Economy of Nationalisation in Britain 1920-1950* (Cambridge, Cambridge University Press, 1995); A.J. Arnold, '"In Service of the State"? Profitability in the British Armaments Industry 1914-1924, *Journal of European Economic History*, Vol.27, No.2 (1998), pp.285-314; D. Edgerton, *Warfare State, Britain 1920-1970* (Cambridge, Cambridge University Press, 2006); S.C. Sambrook, *The Optical Munitions Industry in Great Britain, 1888-1923* (London, Pickering and Chatto, 2013).

there has been limited exploration of the process of technical change in one of the first scientifically influenced industries.[6] Thirdly, studies of Vickers and Armstrong have dominated writing on the industry, given their position as principally armaments companies with diversified interests in steel and shipbuilding, perpetuated by the longer availability of their business records over other companies in the sector.[7] Consequently, there has been a focus on the armaments industry as an adjunct of the shipbuilding industry, with warship production and procurement a prevailing feature.[8] With the exception of Tweedale's work on the wider Sheffield steel industry, prior studies have placed less attention on the importance of Sheffield as not just a productive centre, but perhaps the most important inventive centre for armaments in the country. Previously, attention has been placed on other industrial centres related to armaments, Bastable suggesting that 'the true symbol of British naval power was not the great battleships on the seas but the great armament factories at Elswick.'[9] Nevertheless, it is essential to not overlook that in addition to being connected to shipbuilding, the armaments industry was also an important adjunct of the steel industry. As two of Vickers' directors observed in 1931,

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[6] A basic narrative of the armaments industry which deals with technology in a very broad sense was written in 1945, with little attention paid to the business of armaments. See J.F.C. Fuller, *Armament and History: A Study of the Influence of Armament on History from the Dawn of Classical Warfare to the Second World War* (New York, Charles Scribner's Sons, 1945). In the 1950s, armour production received some attention; see A.D. Stacey, *An Historical Survey of the Manufacture of Naval Armour by Vickers Sons & Co., and their Successors* (Sheffield, Unpublished Typescript, 1956). Some discussion of the interplay between business, innovation and the British government has also been provided by McNeill. See W.H. McNeill, *The Pursuit of Power: Technology, Armed Force and Society Since A.D.1000* (Oxford, Basil Blackwell, 1983), Chapter 8: Intensified Military-Industrial Interaction 1884-1914. More recent general works have also begun to explore the technology and production of armour. See D. C. Oldham, *A History of Rolled Heavy Armour Plate Manufacture* (Sheffield, South Yorkshire Industrial Heritage Society, 2010) and D. Boursnell, *Forging the Fleet: Naval Armour and the Armour Makers, 1860-1916* (Sheffield, Sheffield Industrial Museums Trust Press, 2016).

[7] The main works in this area are J.D. Scott, *Vickers: A History* (London, Weidenfeld and Nicolson, 1962); Trebilcock, *Vickers Brothers*; K. Warren, *Armstrongs of Elswick: Growth in Engineering and Armaments to the Merger with Vickers* (London, Macmillan, 1989); M. J. Bastable, *Arms and the State: Sir William Armstrong and the Remaking of British Naval Power, 1854-1914* (Aldershot, Ashgate, 2004); K. Warren, *Armstrong: The Life and Mind of an Armaments Maker* (Berwick, Northern Heritage, 2011). Davenport-Hines, *Disarmament,* and Packard, *Whitehall* also draw their conclusions based on predominantly examining Vickers. Elsewhere, when Steven Tolliday's work on the British steel industry explores armaments, it too only focuses on Vickers and Armstrong. See S. Tolliday, *Business, Banking and Politics – The Case of British Steel 1918-1939* (Cambridge Mass, Harvard University Press, 1987).

[8] For instance, see S. Pollard, and P. Robertson, *The British Shipbuilding Industry, 1870-1914* (Cambridge, Mass., Harvard University Press, 1979), Chapter 10: The Influence of the State; C. More, 'Armaments and Profits: The Case of Fairfield', *Business History,* Vol.24, No.2 (1982), pp.175-185; Warren, *Armstrongs*; Slaven, 'A Shipyard in Depression'; Singleton, 'Full Steam Ahead'.

[9] Bastable, *Arms and the State,* p.223.

‘Steel is the foundation of the armament business.’[10] Furthermore, writing in the 1920s, John Brown’s chairman Baron Aberconway estimated that before the Great War Sheffield made about 70% of all the armour made for British warships, and 70% of war material made by private companies, including guns, gun forgings, shell and projectiles, and steel for small arms.[11]

Of the five companies involved in the Sheffield armaments industry, Vickers, Brown, Firth, Cammell and Hadfields, the latter four have received limited attention in studies of the British armaments industry, and as already outlined form the core of investigation for this study. Vickers, whose River Don Works were in Sheffield, is excluded for a number of reasons. As already highlighted, much has already been written on the company, and by 1914 Vickers were a large national company with ten productive facilities in the UK. Most importantly, the four companies under investigation were steel companies with a significant interest in armaments, while Vickers evolved into an armaments company with an interest in steel. Such was the diversification of Vickers’ business in the Edwardian period it would be misleading to suggest they were principally a steel company.[12] Viewing the armaments industry as an adjunct of the steel industry is central to this exploration of the Sheffield armaments industry. It is acknowledged that while Brown and Cammell also had access to shipbuilding facilities, the core of their business remained in steel.

Situated in the East End of Sheffield (See Map 1), the companies selected for this research have all been the subject of studies which cover their history, with armaments receiving varying levels of attention.[13] While describing Sheffield as ‘The Arsenal of the World’, the close proximity of each company’s works and research facilities led a contemporary observer to note in 1918 that:

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[10] Quoted in Davenport-Hines, *Disarmament,* p.157.

[11] Lord Aberconway, *The Basic Industries Of Great Britain*, Chapter 3, Part 2: Sheffield Steel, 1927, p.61.

[12] B. Collier, *Arms and the Men: The Arms Trade and Governments* (London, Hamish Hamilton, 1980), p.67. On Vickers, Collier suggests of their expansion plans: ‘it must become not so much a steel firm with a substantial interest in the arms trade as an armament firm with a substantial interest in steel.’

[13] See A.C. Marshall and H. Newbould, *The History Of Firths 1842-1918* (Sheffield, 1925); A. Grant, *Steel and Ships: The History of John Brown’s* (London, Michael Joseph, 1950); A.W. McKears, *The First 100 Years: Hadfields of Sheffield* (Sheffield, Unpublished Duplicate Typescript, 1973); E. Mensforth, *Family Engineers* (London, Ward Lock Ltd, 1981); K. Warren, *Steel, Ships and Men: Cammell Laird and Company 1824-1993* (Liverpool, Liverpool University Press 1998). Maltby’s work on Hadfields’ AGMs also explores armaments issues. See J. Maltby, ‘Hadfields Ltd: Its Annual General Meetings 1903-1939 and their Relevance for Contemporary Social Reporting’, *The British Accounting Review*, Vol.36, No.4 (2004), pp.415-439.

> It is said of the great East End Armaments Works in Sheffield that whilst on one side of the road a firm is inventing an armour-plate that will resist the most formidable piercing shell made, an establishment on the other side of the way is producing a shell against which nothing can possibly stand. It is almost as if the irresistible were meeting the immovable.[14]

This had been true for the previous 20 years. Overall before the Great War, Sheffield was perhaps the world centre of armaments production and research, with licensing agreements and sales across the globe. The two armour plate producers, Brown and Cammell, commenced manufacture in the early 1860s and for more than two decades had a virtual monopoly of supply to the Admiralty. Firth commenced shell and projectile manufacture around the time of the Crimean War, their counterparts in Hadfields experimenting with ordnance production from 1878. The growth of the industry from the late 1880s stemmed from a decision by Jackie Fisher, the Admiralty Director of Naval Ordnance in 1886. Fisher:

> demanded and was accorded the legal right to purchase from private firms any article that the arsenal could not supply quickly or more cheaply. Though no one realised it at the time, this decision soon gave private arms makers an effective monopoly on the manufacture of naval heavy weapons.[15]

This decision saw an expansion in the number of private companies in the armaments industry, with Vickers commencing gun and armour production in Sheffield from 1888 with the passing of the Naval Defence Act the same year. The growth of the industry thereafter was based on the need to expand the facilities for armaments production in Britain. As Ashworth has suggested:

> For warships and armaments the gradually increasing reliance on private enterprise seems to have come more from a need to call on greater productive capacity than from any comprehensive assessment of economic advantages.[16]

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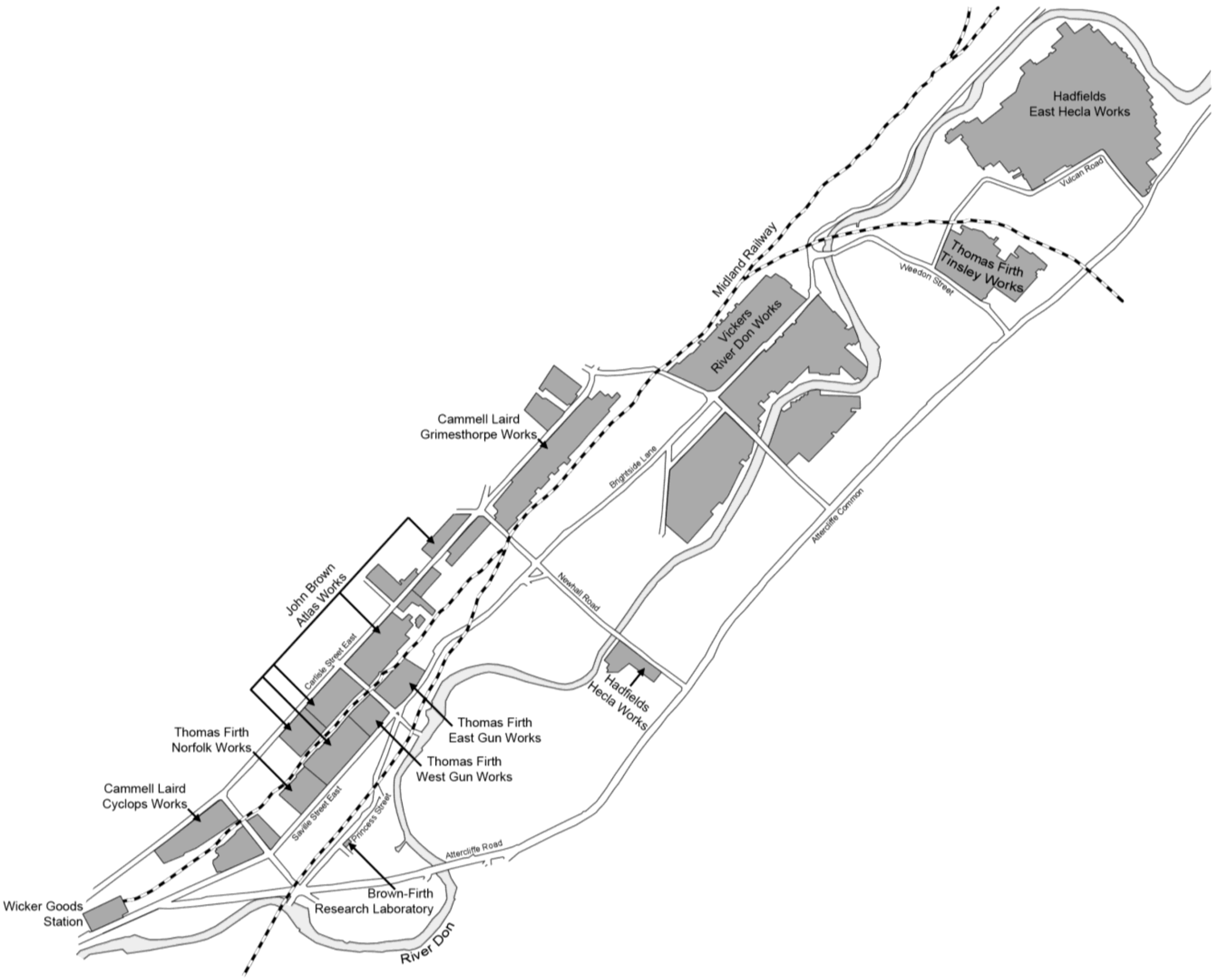
[14] Sheffield City Library (SCL), *Sheffield, The World's Arsenal*, 1918.
[15] McNeill, *Pursuit of Power*, p.271.
[16] W. Ashworth, 'Economic Aspects of Late Victorian Naval Administration', *Economic History Review*, Vol.22, No.3. (1969), pp.491-505.



Map 1: Sheffield East End, 1920. Adapted from Ordnance Survey Map 1924.

The growth and consolidation of the industry in the late Victorian and Edwardian period saw the development of a number of national and international connections in the industry. However, the industry received some criticism during this time of expansion. There were attacks on what was termed the 'International Armaments Trust' by Radicals in the Edwardian period, but much of their evidence was based on speculation and hearsay rather than solid facts.[17] In discussing armaments in the years prior to the Great War, Stevenson has highlighted that:

> There seems little basis for a primarily technological explanation of the intensified competition between about 1910 and the outbreak of war…armaments were viewed more generally as a defensive insurance

[17] Trebilcock, Radicalism.

premium, a deterrent, and an instrument of diplomatic leverage than as the means of military aggression.[18]

The companies involved in armaments manufacture saw what they produced as a symbol of the power of the British Empire and a means of preventing rather than inciting wars.[19]

One of the main reasons the Sheffield armaments industry has not been examined in detail is due to the limited availability of archival sources. Only relatively recently have the records of Sheffield steel companies become obtainable following donations and company closures, and very few have been fully catalogued. During the course of this study the records of Firth were catalogued and made available from Sheffield Archives, along with a limited number of records from Brown covering 1903-24 deposited with the Firth collection in 1993. The records of Hadfields, donated to Sheffield Archives in the early 1980s, and the English Steel Corporation records deposited in 1988 are so extensive they are still being processed by archive staff. Despite covering the late 1920s to the 1960s, the English Steel Corporation collection contains some important records regarding armaments production after the Great War. Finally the records of Cammell, long thought lost following Second World War bombing of their factories, were discovered when their Birkenhead Shipyard was closed in 1993 and consequently deposited at the Wirral Archives Service where a simple box list is available.[20] Without the opening up of these records, this study would not have been possible. However, these records are relatively limited regarding the technology of the industry, and few contemporary records discuss the development of armaments technology in any detail.[21]

In light of this scarcity, patents are used as the only source available which documents the evolution of armaments technology between 1900 and 1930.[22] Much like in the electrical and aviation industries, the filing of patents

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[18] D. Stevenson, *Armaments and the Coming of War, Europe 1904-1914* (Oxford, Clarendon Press, 1996), pp.412-413.
[19] Trebilcock, Legends, p.5.
[20] Tweedale discusses the availability of records relating to the Sheffield Steel industry in *Steel City*, pp.409-411.
[21] There are two exceptions. See Sheffield City Library (SCL), *British Association Handbook and Guide to Sheffield,* 1910, in which Douglas Vickers and Sir Trevor Dawson discuss Armour and Ordnance, and SCL, *The Evolution of the AP Projectile*, 1924.
[22] For a general overview of the British patent system see K. Boehm, *The British Patent System: Administration* (Cambridge, Cambridge University Press, 1967); C.T. Taylor and Z.A. Silberston, *The Economic Impact of the Patent System: A Study of the British Experience* (Cambridge, Cambridge University Press, 1973) and more recently C. MacLeod and G. Radick, 'Claiming

was routine in the armaments industry in the late nineteenth and early twentieth centuries.[23] The use of patents can have its pitfalls, the main critique that they are not ‘synonymous with inventive activity or invention’ and that few inventors ever left records detailing why they invented and in the areas they chose.[24] Patents also only ‘capture the most formalised part of technological knowledge,’ that which has been codified into explicit knowledge to allow its transmission.[25] Nevertheless, with no alternatives patents are the best available means of reconstructing the technological history of the industry. The collection of these records commenced with the identification in company archives of relevant and important patents, which allowed for the correct filings to be found. The development of databases such as EspaceNet has aided the research, as patents can be searched for by inventor and company names where they appear, and also facilitates the discovery of other inventors involved in the development of armaments technology.[26] All of the patents emanating from each company and named inventor during the period of the study were examined to fully explore the relationships between civilian and armaments technology in the industry. After identifying all of the relevant patent records, these were examined chronologically to identify the evolution of technological development and experimentation, and in turn highlight the nuances in designs, knowledge development and areas where civilian knowledge influenced armaments developments, and armaments knowledge was passed back to civilian researchers for further utilisation. This level of analysis facilitated the exploration of technological paths at each company, and added to an overall understanding of the successes and dead-ends discovered in research and development activities.

While this combination of primary sources has only recently been made available to researchers, there are also many secondary works on the industry which can be accessed. Since the inter-war period, much has been written on the armaments industry from a number of perspectives. Following the failure to induce unilateral disarmament in the 1920s a negative literature grew up in the

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Ownership in the Technosciences: Patents, Priority and Productivity’, *Studies in History and Philosophy of Science*, Vol.44, No.2 (2013), pp.188-201.

[23] MacLeod and Radick, Ownership, p.195.

[24] H.I. Dutton, *The Patent System and Inventive Activity During the Industrial Revolution 1750-1852* (Manchester, Manchester University Press, 1984), pp.6-7.

[25] Archibugi and Michie, p.15.

[26] EspaceNet had a database of 90 million patents, all searchable. See worldwide.espacenet.com

following decade which predominantly looked upon the armaments industry as a war-mongering, profiteering conglomerate.[27] Much of this criticism was focused on the belief that the armaments industry caused wars, operated in rings to drive up profits, exercised extreme political influence to secure orders, and bribed foreign governments to buy their products.[28] The German arms giant Krupp also received criticism, though a more balanced literature on the company grew from the 1950s despite discussions of their role in the rearmament of Germany and links to the Nazi party being included.[29] In need of a figure to direct their vitriol against, many writers focused their critique of the industry on Sir Basil Zaharoff, a salesman from Vickers who became the proverbial 'merchant of death'.[30] Zaharoff did himself no favours when he declared in 1933 that 'I make wars so that I can sell arms to both sides.'[31] However, more recent work on Zaharoff has emphasised his prominent role in communicating with the Ottoman Empire during the Great War on behalf of the British Government.[32] Much of the evidence behind this negative press was proved questionable following the 1935-6 *Royal Commission on the Private*

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[27] On disarmament attempts in the 1920s, see A. Webster, 'Making Disarmament Work: The Implementation of the International Disarmament Provisions in the League of Nations Covenant, 1919-1925', *Diplomacy and Statecraft,* Vol.16, No.3 (2005), pp.551-569; A. Webster '"Absolutely Irresponsible Amateurs": The Temporary Mixed Commission on Armaments, 1921-1924', *Australian Journal of Politics and History*, Vol.54, No.3 (2008), pp.373-388; and K. Tenfelde, 'Disarmament and Big Business: The Case of Krupp, 1918-1925', *Diplomacy and Statecraft*, Vol.16, No.3 (2005), pp.531-549.

[28] See for instance F. Brockway, *The Bloody Traffic* (London, Victor Gollancz, 1933); H.C. Engelbrecht and F.C. Hanighen, *Merchants of Death, A Study of the International Armaments Industry* (New York, Dodd, Mead and Company, 1934); G. Seldes, *Iron, Blood and Profit: An Exposure of the World-Wide Munitions Racket* (London, Harper and Brothers Publishers, 1934); P. Noel-Baker, *The Private Manufacture of Armaments* (London, Victor Gollancz, 1937). The negative view of the armaments industry persisted into the 1970s, see for instance A. Sampson, *The Arms Bazaar; The Companies, The Dealers, The Bribes: From Vickers to Lockheed* (London, Stoughton, 1977).

[29] See H. Robertson Murray, *Krupps and the International Armaments Ring: The Scandal of Modern Civilization* (London, Holden and Hardingham, 1914); B. Menne, *Krupp or The Lords of Essen* (London, William Hidge and Company Ltd, 1937); G. von Klass, *Krupps: The Story of an Industrial Empire* (London, Sidgewick and Jackson, 1954); P. Batty, *The House of Krupp* (London, Sector and Warburg, 1966); W. Manchester, *The Arms of Krupp 1587-1968* (London, Michael Joseph, 1969).

[30] On Zaharoff, see G. Davenport, *Zaharoff: High Priest of War* (Boston, Lothrop, Lee and Shepard Company, 1934); R. Neumann, *Zaharoff the Armaments King* (London, Readers Union Ltd, 1938); D. McCormick, *Pedlar of Death: The Life of Sir Basil Zaharoff* (London, Macdonald, 1965); Collier, *Arms and the Men,* Chapter 5: Zaharoff.

[31] Trebilcock, *Vickers*, p.xxxiii

[32] J. Maiolo and T. Insall, 'Sir Basil Zaharoff and Sir Vincent Caillard as Instruments of British Policy towards Greece and the Ottoman Empire during the Asquith and Lloyd-George Administrations 1915-8', *The International History Review*, Vol.34, No.4. (2012), pp.819-839.

Manufacture of and Trading in Arms.[33] During the presentation of their evidence at the commission, unsurprisingly most companies emphasised the technical contributions private manufactures had made to the industry since the 1890s, a detail overlooked in the negative accounts of the industry.

The work of Clive Trebilcock from the late 1960s began to counter the negative stereotypes of the industry.[34] Trebilcock has, correctly, asserted that the companies and directors involved with armaments were not 'merchants of death', but good businessmen, suggesting a general need to 'assess the armament manufactury as a *business* and not as a moral problem.'[35] However, Trebilcock's conclusions are predominantly based on examining Vickers, and on other aspects of armaments production such as cordite. Consequently, there is scope to explore and provide revisions to some of the core elements and arguments advanced by Trebilcock through the case studies utilised in this research.

Overview of Themes

By examining the technology of the industry, the connections between armaments and metallurgy in the use, creation and transmission of knowledge derived from research and development activities at the companies involved will be explored. Furthermore, consideration will be given to the process of innovation in the industry, the approaches taken to developing refinements in the products manufactured, and the importance of connections between people and institutions in the process of research. In this regard, it advances the existence of an innovation system centred on Sheffield.

The technological development of armaments was unlike any other research and development undertaken at the time. As Warren highlights:

> In no field of technology is 'progress' so rapid as in the elaboration of means of mass destruction. The continuing flow of new processes or products requires incorporation into the manufacturing programme;

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[33] For a contemporary analysis of the Royal Commission, see D.G. Anderson, 'British Rearmament and the 'Merchants of Death': The 1935-36 Royal Commission on the Manufacture of and Trade in Armaments', *Journal of Contemporary History*, Vol.29, No.1. (1994), pp.5-37.
[34] Trebilcock, Legends.
[35] Trebilcock, *Vickers*, p.152.

innovation must be slotted into place in the making of complex instruments of war.[36]

Nevertheless, there is scope to expand our understanding with regards how and why armaments companies innovated the way they did. Research into the convergence of armaments and metallurgical technology is an area where more investigation is required to understand the connections between civilian and military research and development activities in private industry. Tweedale has highlighted that:

> almost everything else written about Sheffield steel tends to underrate the impact of armaments. Historians of metallurgy, in particular, have neglected this area, perhaps because they have been reluctant to stress the destructive uses of steel, or because the technology itself is often so inscrutable.[37]

The history of metallurgy owes much to Tweedale's work on Sheffield and the key individuals involved in research and development.[38] As Tweedale has stated, 'By 1900 the science of metallurgy was definitely emerging, though the diffusion of ideas was slow.'[39] In discussing the use of chromium by armaments companies before the Great War, for example, Tweedale has suggested that 'Much of the development work on these steels was highly secret and will probably never be known, but the importance of such research for the development of a superior understanding of the science of steel must have been immense.'[40] Trebilcock has also highlighted that the metallurgical research of armaments companies was decades ahead of their civilian counterparts.[41] Limbaugh's work on the mining of tungsten by the Nevada-Massachusetts

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[36] Warren, *Armstrongs of Elswick*, p.3.
[37] Tweedale, *Steel City*, p.71.
[38] See G. Tweedale, 'Sir Robert Abbott Hadfield F.R.S. (1858-1940), and the Discovery of Manganese Steel', *Notes and Records of the Royal Society of London*, Vol.40, No.1 (1985), pp.63-74; G. Tweedale, 'Transatlantic Specialty Steels: Sheffield High-Grade Steel Firms and the USA 1860-1940' in G. Jones, *British Multinationals: Origins, Management and Performance* (Aldershot, Gower Publishing, 1986); G. Tweedale, *Giants of Sheffield Steel* (Sheffield, Sheffield City Libraries, 1986); G. Tweedale, *Sheffield Steel and America: A Century of Commercial and Technological Interdependence 1830-1930* (Cambridge, Cambridge University Press, 1987); G. Tweedale, 'Science, Innovation and the 'Rule of Thumb': The Development of British Metallurgy to 1945' in J. Liebenau (Eds.), *The Challenge of New Technology – Innovation in British Business Since 1850* (Aldershot, Gower, 1988); G. Tweedale, 'The Business and Technology of Sheffield Steelmaking' in C. Binfield, R. Childs, R. Harper, D. Hay, D. Martin and G. Tweedale, *The History of the City of Sheffield 1843-1993 Volume 2: Society* (Sheffield, Sheffield Academic Press, 1993).
[39] G. Tweedale, 'Science, Innovation and the 'Rule of Thumb', p.68.
[40] G. Tweedale, 'Science, Innovation and the 'Rule of Thumb', p.73.
[41] See Trebilcock, Spin-Off; Trebilcock, Science.

Company equally stresses that 'as steel metallurgy advanced, so did experiments to improve arms and armour by using special alloys of nickel, manganese, chrome, tungsten and other materials.'[42] The influence of armaments research and development on metallurgy has been acknowledged elsewhere, Pollard stating that 'metallurgical improvements emerged out of the rivalry of the armaments producers, with Vickers and Armstrongs in the lead.' [43] However, there has been limited discussion or detail provided to what these metallurgical improvements are, and how they influenced future special steel developments. A more systematic review of research and development in armaments, steel and metallurgy is required, and forms a major element of this study.

The terms alloy steels and special steels are used in this study and require an introduction. Robert Abbott Hadfield, arguably the father of the modern age of alloy steels, offers the following definition:

> It is usual…to reserve the term "alloy steel" or "special steel" for steels which owe their properties to the presence of elements other than carbon, even though carbon still plays a vitally important part in determining the characteristics of the alloy… From the practical standpoint the importance of alloy steels lies in the fact that they yield a greater range of mechanical properties than can be obtained in simple carbon steels, whilst they also yield either new physical properties or new combinations of properties.[44]

While armaments were central to the evolution of knowledge related to metallurgy and alloy steels in the early 1900s, they drew on the developments in this area since the 1860s. In experiments to advance tool steels, Robert Mushet discovered in 1868 that the addition of 7% tungsten to the composition of steel created a 'self-hardening' tool steel, later marketed as 'R. Mushet's Special Steel'.[45] This was certainly one of the major early breakthroughs in the development of metallurgy. Writing in 1925, Hadfield stressed that 'In relation to our present-day knowledge, the armourer working with carbon steels and the

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[42] R.H. Limbaugh, *Tungsten in Peace and War 1918-1946* (Reno and Las Vegas, University of Nevada Press, 2010), p.19.
[43] S. Pollard, *Britain's Prime and Britain's Decline: The British Economy 1870-1914* (London, Edward Arnold, 1989), p.204.
[44] R.A. Hadfield, *Metallurgy and its Influence on Modern Progress* (London, Chapman and Hall, 1925), pp61-2.
[45] Tweedale, *Steel City*, p.92.

Mushets working with self-hardening alloy steel occupied the same plane of successful empiricism.'[46] Hadfield's research was particularly important to the early development of alloy steels. In 1882, his novel addition of 12% manganese to steel led to the first major alloy steel to go into production, its hard wearing properties useful in the production of tramway rails and crushing machinery.[47] Hadfield also invented silicon steel in 1884, the material finding widespread use in the electrical industry and in the manufacture of electrical transformers.[48]

A key feature of the armaments industry from 1888 was that 'weapons technology evolved mostly from the research and development efforts of private entrepreneurs.' [49] Innovation was central to the continued vitality of the business, with research and development encouraged by the British Government. Consequently, companies in the industry committed themselves to a perpetual cycle of experimentation and investigation to maintain their status as armaments producers. As Trebilcock has suggested in his study of Vickers:

> Failure to innovate would be ruinous, failure to keep abreast with technological advance would be 'destructively unprofitable', failure to maintain quality would mean a customer lost – and when a customer could be a whole country, quality was at a premium.[50]

Given this supportive market environment, innovation became routine, requiring a 'dependable capability in research and development' towards consistent scientific renewal rather than perfection.[51] However, there is limited discussion regarding the complexity of the connections between armaments and metallurgical developments in previous studies. Gale has placed some acknowledgement on the link between armaments and metallurgy, stating that:

> In the last twenty years or so of the nineteenth century numerous experiments were also made on armour plate steels and on armour-piercing alloys, which added considerable information to the store which was building up on the effect of alloying various elements with iron. Those were the days of the heavy capital ship in the world's navies, and it was for the arming and armouring of such ships that much of the

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[46] Hadfield, p.47.
[47] For more details see Hadfield, Chapter 7: Manganese Steel.
[48] For more details see Hadfield, Chapter 8: Silicon Steel.
[49] Bastable, *Arms and the State,* p.170.
[50] Trebilcock, *Vickers*, p.xxxii.
[51] Trebilcock, *Vickers*, p.3.

experimental work was done. Its main significance historically, however, is in the information it made available on nickel-steel alloys.[52]

Elsewhere, there have been discussions regarding the emergence of metallurgy as being unguided by systematic research. Rosenberg has suggested that:

> the modern science of metallurgy had its origins in the need to solve practical problems that were associated with the emergence of the modern steel industry…metallurgy can be characterised as a sector in which the technologist typically "got there first," that is, developed powerful technologies, or alloys, in *advance of* systematised guidance by scientists.[53]

Nelson too highlights this form of metallurgical emergence.[54] More generally, Edgerton has called for more firm and sector based explorations of research and development as a part of business history. Furthermore:

> Many innovations are based on combinations of different sciences and technologies, combinations which might be more easily identified where they were already part of the same firm or research laboratory… It might well be that firms produce firm-specific scientific and technological theory which can then be used to develop new products in a particular way, while another firm might have different theory and innovate in a different way – it is not therefore a question of being first with a theory.[55]

This combination of different sciences was a key element of innovation with steel, metallurgy and armaments. More recently, Edgerton has highlighted how the history of technology has become a sector of study in its own right, and that 'unfashionable' history disciplines such as business, economic and military history need to be further engaged with as part of technological investigations.[56] In this regard, elements of this study may be considered interdisciplinary; exploring the connections between business and technology in what was one of

[52] W.K.V. Gale, *The British Iron and Steel Industry: A Technical History* (David & Charles, Newton Abbott, 1967), p.128.
[53] N. Rosenberg, *Exploring the Black Box* (Cambridge, Cambridge University Press, 1994), p.20.
[54] R.R. Nelson, *The Sources of Economic Growth* (Cambridge Mass., Harvard University Press, 1996), p.145.
[55] D.E.H. Edgerton, 'Science and Technology in British Business History', *Business History*, Vol.29, No.1 (1987), pp.94-5.
[56] D. Edgerton, 'Innovation, Technology, or History: What is the Historiography of Technology About?', *Technology and Culture*, Vol.51, No.3 (2010), p.697.

the first examples of a systematic, scientifically informed approach to research and development.

Central to exploring the technology of armaments is Trebilcock's concept of technological spin-off, which suggests that the development of armaments had a strong influence on the development of complementary civilian technologies in Britain and Europe.[57] However, Trebilcock's ideas require qualification. While extensive in the examples provided which demonstrate spin-off between industrial sectors, there are areas where Trebilcock offers observations regarding spin-off and armaments technological development where further research can provide key refinements to the paradigm, principally at the level of the company. Firstly, highlighted in the opening definition of spin-off is that technological innovations may 'merely travel the short distance between the weapons department of the munitions firm and the commercial engineering department often maintained by such organizations', though limited examples of such interactions are provided.[58] Secondly, only briefly mentioned is the possibility of civilian industries influencing the development of armaments technology, with metallurgical, machine tool and chemical engineering industries highlighted. Trebilcock advances that 'a two-way process was involved: arms technique had to draw upon these disciplines before, in its turn, it could hand down useful instructions to industry at large.'[59] This potential use of civilian knowledge to assist the research and development mechanisms at armaments companies is not explored further. The cases examined in this study will consider the extent to which refinements to Trebilcock's definition of spin-off can be made. Furthermore, to move beyond this definition of spin-off, this phenomenon may function as a two-way interaction between civilian and armaments research and development at a company. The evolution of armaments and commercially based metallurgy was part of a continuum, whereby the two fields could continually draw on each other for knowledge to drive forward the next product-based technological advance from either side of the industry. Principally, this is related to the utilisation of knowledge, and the individuals involved in its creation, transmission and usage. The spin-off of knowledge from research dead-ends also requires consideration, the examples

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[57] C. Trebilcock, Spin-Off.
[58] Trebilcock, Spin-Off, pp.475-6.
[59] Trebilcock, Spin-Off, p.479.

found from reconstructing the technological history of the industry which highlight where ideas failed to go into production, but useful lessons were learned. Nonaka and Takeuchi have suggested that 'to create new knowledge means quite literally to re-create the company and everyone in it in an ongoing process of personal and organisational self-renewal.'[60] There is also a literature related to a knowledge based view of the firm, which reduces what a company does to simply the utilisation of knowledge and its exchange, though this is somewhat limited on how companies create knowledge.[61]

As part of Trebilcock's analysis of spin-off, he suggests that an 'interest in the scientific basis of manufacture set the armourers apart from the conservative mass of British industrialists and qualified them to act as technological leaders.'[62] One critique levelled against the spin-off paradigm drew attention to the monopolisation of nickel supplies by the armaments industry from their membership of the Steel Manufacturers Nickel Syndicate. In response, Trebilcock referred to the commercial activities of the armaments companies and how their access to civilian markets promoted the use of nickel in the manufacture of alloy steels.[63] One, more complex version of the spin-off paradigm has been suggested by Samuels, who examined the concept in relation to the development of the Japanese military.[64] The benefits of spin-off

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[60] I. Nonaka and H. Takeuchi, *The Knowledge Creating Company: How Japanese Companies Create the Dynamics of Innovation* (Oxford, Oxford University Press, 1995), p.10.
[61] See K.R. Conner, 'A Historical Comparison of the Resource-Based Theory and Five Schools of Thought Within Industrial Organisation Economics: Do we Have a New Theory of the Firm?', *Journal of Management,* Vol.17, No.1 (1991), pp.121-154; B. Kogut and U. Zander, 'Knowledge of the Firm, Combinative Capabilities, and the Replication of Technology', *Organization Science*, Vol.3, No.3 (1992), pp.383-397; R.M. Grant, 'Towards a Knowledge-Based Theory of the Firm', *Strategic Management Journal*, Vol.17, Winter Special Issue (1996), pp.109-122; R.M. Grant, 'Prospering in Dynamically-Competitive Environments: Organizational Capacity as Knowledge Integration', *Organization Science*, Vol.7, No.4 (1996), pp.375-387; J.C. Spender, 'Making Knowledge the Basis of a Dynamic Theory of the Firm', *Strategic Management Journal,* Vol.17, No.S2 (1996), pp.45-62; K.R. Connor and C.K. Prahalad, 'A Resource Based Theory of the Firm, Knowledge Versus Opportunism', *Organization Science*, Vol.7, No.5 (1996), pp.477-501; K. Sveiby, 'A Knowledge Based Theory of the Firm to Guide in Strategy Formulation', *Journal of Intellectual Capital*, Vol.2, No.4 (2001), pp.344-358; J. Nickerson and T. Zenger, 'A Knowledge-Based Theory of the Firm: The Problem Solving Perspective', *Organization Science*, Vol.15, No.6 (2004), pp.617-632.
[62] Trebilcock, Spin-Off, p.481.
[63] D.G. Paterson, '"Spin-Off" and the Armaments Industry Comment', *Economic History Review*, Vol.24, No.3 (1971), pp.463-464; C. Trebilcock 'Rejoinder' *Economic History Review*, Vol.24, No.3 (1971), pp.464-468. On the Steel Manufacturers Nickel Syndicate, see G. Boyce, 'The Steel Manufacturers' Nickel Syndicate Ltd., 1901-39: Assessing the Conduct and Performance of a Cooperative Purchasing Organisation', *Australian Economic History Review*, Vol.38, No.2 (1998).
[64] R.J. Samuels, *Rich Nation, Strong Army* (London, Cornell University Press, 1994), Chapter 1: The Strategic Relationship of the Military and Civilian Economies. Samuels proposes a framework which incorporates 'spin-on' and 'spin-away' to the spin-off paradigm.

from the international business ventures of the armaments industry have also been explored by Trebilcock.[65]

The process of armaments technological evolution is further explored through Rosenberg's notion of path dependency, which provides a framework for examining the development of armaments technologies, and the integration of civilian technology into armaments production. Rosenberg's approach highlights that 'technological knowledge grows in distinctly path-dependent ways' and that a technological path begins with the development of a major innovation. A major innovation has the potential to trigger the development of a number of sub-innovations which serve to refine and advance the performance of the initial major innovation. As Rosenberg states, such developments 'involve endless minor modifications and improvements in existing products, each of which is of small significance but which, cumulatively, are of major significance'.[66] Given the process of development in the armaments industry, we will be able to apply this notion of technological path dependence in order to fully understand the research and development history of the industry.

The individuals involved in the process of technical development also require consideration. As Gospel has suggested, we should not overlook that 'engineers and technical staff [have a] key role in the process of developing and implementing technological change.'[67] The predominant force for technological change in the armaments industry was the individual inventor-cum-technocrat, dedicated to the perfection of a design to fulfil a narrowly defined issue and predisposed to explore and satisfy every element of its design and function to absolution. In the pursuit of such an end, inventors frequently built on their prior experimentation and knowledge to create new sub-innovations which in isolation had limited function but when combined with other sub-innovations created a finished product. Consequently it is possible to view the path-dependent development of armaments technology as inseparable from the research and development activities of its principal inventor. Consequently, the continued technological vitality of an armaments company may be dependent upon the continuity of its research team. Commercially, to be able to profit from their initial invention and designs, the inventor-cum-technocrat had two options;

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[65]Trebilcock, British Armaments and European Industrialization.
[66] Rosenberg, *Black Box*, pp.14-16.
[67] H.F. Gospel, 'Industrial Training and Technological Innovation: An Introduction' in H.F. Gospel, *Industrial Training and Technological Innovation* (London, Routledge, 1991), p.1.

they could employ some entrepreneurial skill and commence manufacture themselves or licence the patent rights to a company, which often led to a directorship at the firm. However:

> '…we should not too easily equate technological innovation with business entrepreneurship. A new technology, however brilliantly and elegantly designed, however efficiently it performs, does not necessarily guarantee being acknowledged as superior, nor does it necessarily bring business success.'[68]

Lipartito has suggested that technology was 'one of the key determinants of business strategy' and that business historians have to ask what choices companies had in making the technological decisions which guided their strategy.[69] He also highlights that 'Innovative firms do not merely select from available technologies, they participate in the process of innovation, including setting the basic parameters that determine success and bringing artefacts and knowledge together with ambience.'[70] The model Lipartito advances places the company 'at the crucial juncture points of all the interests that converge on technology.'[71] In this regard, exploring the nature of inter-firm links is central to any examination of armaments technology.

The connections between armaments companies were an important element of their technological development, inter-firm competition also a proven driver of technological innovation in the industry.[72] As Nelson suggests, 'even among private for-profit entities, there is some sharing and openness about technology and other matters as well as proprietary rivalry.[73] To explore this further the research utilises the concept of innovation systems.[74] Building on the

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[68] Bastable, *Arms and the State*, p.109.
[69] K. Lipartito, 'Innovation, the Firm, and Society', *Business and Economic History*, Vol.22, No.1 (1993), p.93.
[70] Lipartito, Innovation, p.96.
[71] Lipartito, Innovation, p.102.
[72] Packard, *Whitehall,* p.95.
[73] R.R. Nelson, *The Sources of Economic Growth* (Cambridge Mass., Harvard University Press, 1996), p.4.
[74] On innovation systems, see R.R. Nelson, 'National Innovation Systems: A Retrospective on a Study', *Industrial and Corporate Change*, Vol.1, No.2 (1992), pp.347-374; R.R. Nelson and N. Rosenberg, 'Technical Innovation and National Systems' in R.R. Nelson, *National Innovation Systems: A Comparative Analysis* (Oxford, Oxford University Press, 1993); W. Walker, 'National Innovation Systems: Britain' in R.R. Nelson, *National Innovation Systems: A Comparative Analysis* (Oxford, Oxford University Press, 1993); C. Freeman, 'The "National System of Innovation' in Historical Perspective', *Cambridge Journal of Economics*, Vol.19, No.1 (1995), pp.5-24; R. Lloyd-Jones and M.J. Lewis, 'Technological Pathways, Modes of Development and the British National Innovation System, Examples from British Industry 1870-1914', in L. Tissot and B. Veyrassat, *Technological Trajectories, Markets, Institutions, Industrialised Counties, 19th-*

work of Nelson and Rosenberg, innovation is viewed as 'the processes by which firms master and get into practice product designs and manufacturing processes that are new to them, if not the universe or even to the nation,' while the system element emphasises 'a set of institutional actors that, together, plays the major role in influencing innovative performance.'[75] Central to the concept is the value of connections between people, companies, universities and governments as a part of the innovation process. As Archibugi and Michie highlight, 'crucial to the definition of a national system is how the different parts, such as universities, research centres, business firms and so on, interact with each other.'[76] However, Nelson and Rosenberg's work is chiefly concerned with *national* innovation systems, a concept they also stress as potentially too broad.[77] To examine an innovation system in the Sheffield armaments industry, viewing the system as national does not accurately reflect the connections developed by actors in the industry, which had a local core in Sheffield and links across the globe. In this regard, more recent work on regional or local innovation systems does not reflect their experience either. Howells highlights that the concepts 'can arguably be equally applied at a regional or local level' and provides an additional layer to the national systems of innovation approach rather than supplanting them.[78] Sub-national innovation systems also 'represent crucial arenas for localised learning and tacit know-how sharing.'[79] Furthermore, Nelson has highlighted that 'innovation systems are not neatly divided by national borders.'[80] A trans-national innovation system with a concentrated local core in Sheffield is more appropriate, though a geographically bounded

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20th Centuries: From Context Dependence to Path Dependency (Bern, Peter Lang, 2001); D. Archibugi and J. Michie, 'Technological Globalisation and National Systems of Innovation: An Introduction', in D. Archibugi and J. Michie, *Technology, Globalisation and Economic Performance* (Cambridge, Cambridge University Press, 1997); D. Archibugi, J. Howells and J. Michie, 'Innovation Systems and Policy in a Global Economy' in D. Archibugi, J. Howells and J. Michie, *Innovation Policy in a Global Economy* (Cambridge, Cambridge University Press, 1999); G. Dosi, 'Some Notes on National Systems of Innovation and Production, and their Implications for Economic Analysis' in D. Archibugi, J. Howells and J. Michie, *Innovation Policy in a Global Economy* (Cambridge, Cambridge University Press, 1999).

[75] Nelson and Rosenberg, Innovation, p.4.

[76] Archibugi and Michie, Technological Globalisation, p.4.

[77] Nelson and Rosenberg, Innovation, p.5.

[78] J. Howells, 'Regional Systems of Innovation?' in D. Archibugi, J. Howells and J. Michie, *Innovation Policy in a Global Economy* (Cambridge, Cambridge University Press, 1999), p.67, p.86. On non-national innovation systems, see also D. Archibugi, J. Howells and J. Michie, Innovation Systems.

[79] Howells, Regional Systems, p.78.

[80] R.R. Nelson, 'A Retrospective' in R.R. Nelson, *National Innovation Systems: A Comparative Analysis* (Oxford, Oxford University Press, 1993), p.506.

description of the links between actors does not truly reflect the international nature of the industry. Armaments represent an example of the transmission of technology across national borders, counter to the suggestion that 'technology is not easily transferable across countries'[81] To dispense with a spatially bounded definition, the simpler notion of a 'technological innovation system' is most appropriate, with the addition of a description of the technologies involved.[82] For this study the label 'armaments-metallurgy-steel innovation system' is used to describe the important connections between actors in the industry. When exploring an innovation system, it is imperative to understand that 'systems are made up of the interactions between the actors…in a system. Without any interaction between actors…it is difficult to accept that a system exists.'[83] Two additional points also require attention; firstly that systems can evolve over time, and 'personal capitalism was a component part of the British NIS during the second industrial revolution.'[84] Both of these aspects are incorporated into this study.

In production, the armaments industry involved 'large-scale batch, rather than continuous assembly line production'.[85] Scranton highlights that 'batch versatility was crucial to the introduction of crucible and tool steels and an array of specialty alloys.'[86] It is no coincidence that all of these examples were introduced in the Sheffield industries, where batch production became a core element of the area's commitment to the manufacture of specialised products. As companies diversified into armaments production, batch production techniques were transferred and became central to the specialised nature of armour plate and projectile manufacture. Where armaments differed from other uses of batch production was in the specialisation of their machinery, which resembled a producer utilising facilities to accelerate standardised products

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[81] D. Archibugi and J. Michie, 'Technology and Innovation: An Introduction', *Cambridge Journal of Economics,* Vol.19, No.1 (1995), p.3.

[82] Archibugi and Michie discuss the idea of 'Technological systems versus national systems?' in Archibugi and Michie, Technological Globalisation, pp.12-13. They also highlight that 'it appears to be the case…that both technology-specific and nation-specific factors shape the innovation process.'

[83] D. Archibugi, J. Howells and J. Michie, Innovation Systems, p.7.

[84] D. Archibugi, J. Howells and J. Michie, Innovation Systems, p.7; Lloyd-Jones and Lewis, Technological Pathways, p.136.

[85] Warren, *Armstrongs of Elswick*, p.1.

[86] P. Scranton, 'Diversity in Diversity: Flexible Production and American Industrialization, 1880-1930', *Business History Review*, Vol.65, No.1 (1991), p.32.

rather than the general machinery favoured for batch flexibility.[87] This was the curse of the armourer; so specialised was their plant that adaptation, central to batch production approaches, was only rarely possible and with extensive modifications required. The goal for the armaments companies was the utilisation of their productive facilities for commercial and armaments production, though this was increasingly difficult due to the omnipresent need for accuracy and uniformity during a production run. Much like a blacksmiths in the Middle Ages, who could use their furnaces and equipment to produce fire grates or shoe horses, and quickly use the same facilities to make swords and suits of armour, flexible adaptability and specialisation were at the core of the industry. This level of adaptability required each company to understand the resources at their disposal.[88] Internally, the resources of a company were central to their successful utilisation of new technology, new techniques and new knowledge. A company's use of resources for another purpose may involve the existence of dynamic capabilities, which reflect the ability of a company to 'integrate, build and reconfigure internal and external competences to address rapidly changing environments.'[89] The maintenance of dynamic capabilities also requires entrepreneurial management.[90]

Building on the technological development of the industry, the notion of Sheffield as an armaments focused industrial district is advanced. With the small number of companies in the Sheffield armaments industry, this group can be described as a 'capsule' network, one which is 'relatively small in

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[87] Scranton, Diversity, p.38.

[88] On the Resource Based View (RBV), see E. Penrose, *The Theory of the Growth of the Firm* (Oxford, Oxford University Press, 1959); B Wernerfelt, 'A Resource-Based View of the Firm', *Strategic Management Journal*, Vol.5, No.2 (1984), pp.171-180; M.A. Peteraf, 'The Cornerstones of Competitive Advantage: A Resource-Based View', *Strategic Management Journal*, Vol.14, No.3 (1993), pp.179-191; B. Wenerfelt, 'The Resource-Based View of the Firm: Ten Years After', *Strategic Management Journal,* Vol.16, No.3 (1995), pp.171-174; R.L. Priem and J.E. Butler, 'Is the Resource-Based "View" a Useful Perspective for Strategic Management Research?', *Academy of Management Review,* Vol.26, No.1 (2001), pp.22-40; and J.B. Barney, 'Is the Resource-Based "View" a Useful Perspective for Strategic Management Research? Yes', *Academy of Management Review,* Vol.26, No.1 (2001), pp.41-56.

[89] D.J. Teece, G. Pisano, A. Shuen, 'Dynamic Capabilities and Strategic Management', *Strategic Management Journal*, Vol.18, No.7 (1997), p. 516. See also D. Teece and G. Pisano, 'The Dynamic Capabilities of Firms: An Introduction', *Institutional and Corporate Change*, Vol.3, No.3 (1994), pp.537-556.

[90] D.J. Teece, 'Explicating Dynamic Capabilities: The Nature and Microfoundations of (Sustainable) Enterprise Performance', *Strategic Management Journal*, Vol.28, No.13 (2007), p.1346

membership, self-contained and impermeable.'[91] The small number of members in the group may also promote trust among the actors, though Popp and Wilson have suggested that such high-trust networking 'could shade into collusive behaviours and attitudes, reducing the responsiveness of firms and districts.'[92] Finally, from the technological development of the members of the industry the notion of Sheffield as a knowledge cluster can be explored. In a knowledge cluster, technological information central to the development of an industry becomes commonly known among all actors in the grouping.[93]

The limited market for armaments, only purchased by national governments for their military services, made marketing the quality of a product and service paramount. Faced with a monopsonist British government, the armaments companies developed what Trebilcock describes as special relationships.[94] This terminology is used for this research for continuity, with the caveat that 'special' is used only to signify an unusual and distinctive relationship rather than something exceptional for the companies involved. The establishment and maintenance of these relationships required a close association of personnel, with ex-government and military appointments as company directors a common feature of the industry. The research considers the power relationship between the state and private industry in the building and development of these connections, and if any companies were viewed more favourably by the government. The evolving nature of this relationship is also considered beyond the Great War, with the decline of the industry requiring the protection of armaments capacity by the British Government. The international market, where the Sheffield armaments industry was highly active, also presented a number of challenges for the companies involved. The strategies employed for finding, exploiting and maintaining new foreign customers and the impact on the armaments companies business is explored in the study. The marketing of technology and the licensing agreements entered into by the

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[91] A. Popp, S. Toms, and J. F. Wilson, 'Industrial Districts as Organisational Environments: Resources, Networks and Structures', *Management and Organisational History*, Vol.4, No.1. (2006),.

[92] A. Popp, and J.F. Wilson, 'Districts, Networks and Clusters in England: An Introduction' in A. Popp, and J.F. Wilson (Eds.) *Industrial Clusters and Regional Business Networks in England 1750-1970,* (Aldershot, Ashgate, 2003), p.15.

[93] S. Pinch, N. Henry, M. Jenkins and S. Tallman, 'From 'Industrial Districts' to 'Knowledge Clusters': A Model of Knowledge Dissemination and Competitive Advantage in Industrial Agglomerations', *Journal of Economic Geography*, Vol.3, No.4 (2003).

[94] Trebilcock, Cordite. See also Davenport-Hines, Marketing.

industry is also explored, with the use of printed marketing materials and brand names a usual method by which companies differentiated their products from competitors.

Management of the industry is an omnipresent feature which has links to the other themes of this study. Of importance is management's role in exploring strategies to defend against the uncertain market for armaments with the British government. In addition to developing technological and marketing capabilities, this theme will also consider management's role in the development of the inter-company relationships and wider collaboration in the industry, the development of director networks and the use of joint business ventures. Any discussion of management in British business history stems from the work of Alfred Chandler, who has explored the relative decline of British industry in relation to the persistence of personal capitalism. The general view presented suggests that Britain remained tied to personal forms of management, and failed to invest in new production techniques, salaried managers and appropriate marketing mechanisms.[95] Chandler has also used the decline of the armaments industry after the Great War to demonstrate 'continued failure in the older industries.'[96] As Tweedale has stressed, using mass production as the yardstick against which industrial efficiency is measured certainly did not apply to the Sheffield steel industry.[97] Chandler's approach to business history, focusing on the emergence of big business and viewing the multidivisional form of American enterprises as the ideal organisational form has come under criticism since its publication.[98] Despite this disdain for the personally managed and family firm, further research has highlighted the persistence of family firms in the US, Japan and Germany at the same time as Britain and its perceived decline.[99] Family firms are now recognised as representing the majority of businesses worldwide and the scholarship on family businesses is increasing across a number of

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[95] See A.D. Chandler, *Scale and Scope: The Dynamics of Industrial Capitalism* (Cambridge, Mass., Harvard University Press, 1990), Chapter 1: The Modern Industrial Enterprise.
[96] Chandler, *Scale and Scope*, pp.341-4.
[97] Tweedale, *Steel City,* p.17.
[98] See R.A. Church, 'The Limitations of the Personal Capitalism Paradigm', *Business History Review*, Vol.64, No.4 (1990), pp.703-710; B. Supple, 'Scale and Scope: Alfred Chandler and the Dynamics of Industrial Capitalism', *Economic History Review,* Vol.44, No.3 (1991), pp.500-514; D.J. Teece, 'The Dynamics of Industrial Capitalism: Perspectives on Alfred Chandler's Scale and Scope', *Journal of Economic Literature*, Vol.31, No.1 (1993), pp.199-205; J.F. Wilson, *British Business History, 1720-1994* (Manchester, Manchester University Press, 1995); D.J. Jeremy, *A Business History of Britain 1900-1990s* (Oxford, Oxford University Press, 1998).
[99] R. Church, 'The Family Firm in Industrial Capitalism: International Perspectives on Hypotheses and History', *Business History*, Vol.35, No.4 (1993), pp.17-43.

disciplines.[100] Development based on adapting the Chandlerian paradigm to the study of British business by Toms and Wilson has drawn attention to the significance of external relationships and industrial districts to the British experience.[101] The Harvard school of business history has perpetuated notions of British industrial and entrepreneurial decline in the wake of the Chandlerian paradigm, including the work of Dintenfass, and Elbaum and Lazonick.[102] This view has been challenged in a technological context by Edgerton, who stresses that once we acknowledge that relative decline is not the same as doing badly, a new view of Britain emerges.[103] The frequency of personally managed companies in Sheffield has also been explored by Lloyd-Jones and Lewis, who highlight that:

> Sheffield firms in the specialty-steel sector did invest in manufacturing and marketing, but their reluctance to invest in managerial hierarchies that would undermine their personal control did not inhibit their business success.[104]

Into this specialty-steel bracket may appropriately be placed Brown, Cammell, Firth and Hadfields, their armament output the pinnacle of special steels technology before the Great War. However, the need to recruit specialists and the industry's evolving links with the state through the use of ex-government and military personnel may lead to a further revision of the notion of British industrial decline and personal capitalism. The technology involved and the markets available to armaments manufacturers were both exceptionally specialised and required appropriate investments in people and knowledge to exploit the limited commercial scope for their products. Overall, armaments companies do not fit the general 'failure' model of family business. In exploring

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[100] A. Colli, C. Howorth and M. Rose, 'Long-term Perspectives on Family Business', *Business History*, Vol.55, No.6 (2013), p.845.

[101] S. Toms and J.F. Wilson, 'Scale, Scope and Accountability: Towards a New Paradigm of British Business History', *Business History* Vol.45, No.4 (2003), pp.1-23. For a critique, see R. Lloyd-Jones and M.J. Lewis, 'A New Paradigm of British Business History: A Critique of Toms and Wilson', *Business History*, Vol.49, No.1 (2007), pp.98-105, and S. Toms and J.F. Wilson, 'Scale, Scope and Accountability: A Response to Lloyd-Jones and Lewis', *Business History*, Vol.49, No.1 (2007), pp.106-111.

[102] M. Dintenfass, *The Decline of Industrial Britain 1870-1980* (London, Routledge, 1992); B. Elbaum and W. Lazonick, 'An Institutional Perspective on British Decline' in B. Elbaum and W. Lazonick (Eds.) *The Decline of the British Economy* (Oxford, Clarendon Press, 1986), pp.1-17.

[103] D. Edgerton, *Science, Technology and the British Industrial 'Decline', 1870-1970* (Cambridge, Cambridge University Press, 1996), p.67.

[104] R. Lloyd-Jones and M.J. Lewis, 'Personal Capitalism and British Industrial Decline: The Personally Managed Firm and Business Strategy in Sheffield 1880-1920', *Business History Review*, Vol.68, No.3 (1994), pp.364-411. p.408 quote

Vickers, Trebilcock notes they did not 'display the familiar symptoms of capital shortage, or technological lag, or entrepreneurial deficiency, or small size, or failure to escape from [their] family origins.'[105] This study will explore the extent to which Trebilcock's conclusions can also be applied across the Sheffield armaments industry.

The Sheffield Armaments Industry in 1900

In 1900 the Sheffield Armaments industry had begun to build the international and inter-company connections from which their position as the centre of world armaments technology and production would grow (See Figure 0.1). Acquisitions enabled Vickers and Brown to extend into shipbuilding, and Firth to commence manufacture of projectiles in the United States. The three armour plate manufacturers also had connections to the Harvey United Steel Company, the first group of its kind to co-ordinate the use of armaments technology and the collection and payment of royalties. Within Sheffield, the first connections between technocrats and companies related to projectile technology had begun to form, with Hadfields at the centre. These connections will be explained and elaborated on in more detail in the chapters which follow. The first two chapters in this study will explore the advancement of armaments technology between 1900 and 1914. Chapter one focuses on the evolution of the armour piercing projectile, the connections between companies developed and the marketing of the technology. Chapter two examines armour plate technology, the emergence of metallurgical knowledge from armaments research, and the development of an armaments-metallurgy-steel innovation system with Sheffield at its centre. The second two chapters explore the business and management of armaments during the same period. Chapter three explores the links between the Sheffield armaments industry and the British Government, examining the business and directorships of each company and the nature of special relationships between the state and private industry. Chapter four studies the defensive measures implemented by the Sheffield armaments industry to counter the general uncertainty of the industry, though the development of the Coventry Ordnance works, and both individual and collaborative explorations of foreign markets.

[105] Trebilcock, *Vickers*, p.xxv.

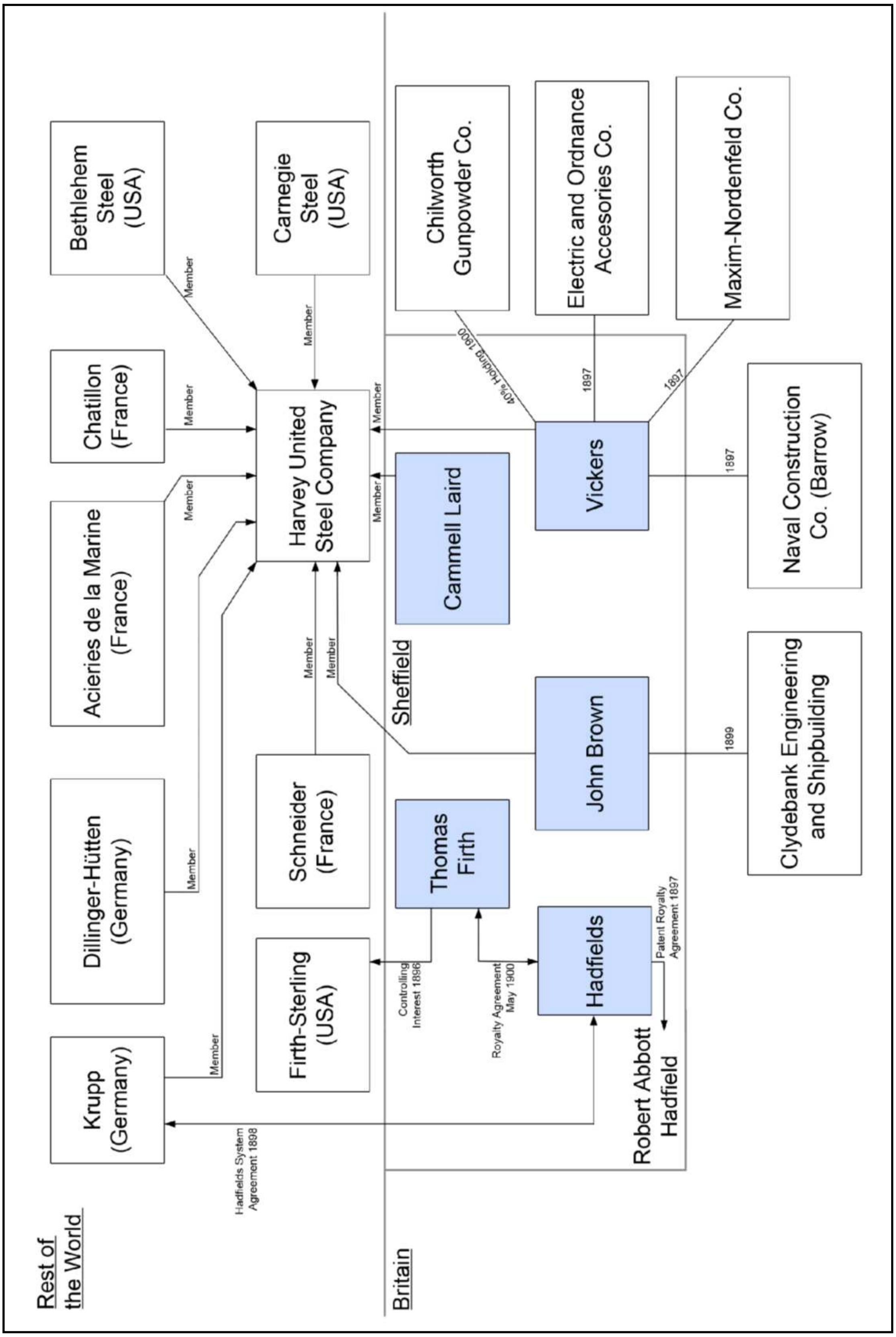

Figure 0.1: The Sheffield Armaments Industry in 1900

Finally, the last two chapters examine at the armaments business from 1914 to 1930. Chapter five considers the utilisation and evolution of armaments technology during the Great War and the decade after, exploring productive developments, the research required for updating armour piercing projectiles after the Battle of Jutland, and the use of knowledge developed from armaments in alloy steels after the conflict. Chapter six investigates the decline of the industry following the Great War, the death of special relationships, the uncertain business environment, and the managerial stagnation of the industry in the 1920s.

Chapter 1: Armaments Technology 1900-1914 – The Evolution of the Armour Piercing Projectile

Commenting on the market-cum-technological environment in which the British armaments industry operated in 1900, Bastable has suggested that:

> The production of naval armaments acquired a strategic, political, economic and cultural momentum on a global scale by the turn of the century. Management of the huge industrial armaments companies occupied an important place in the vast military-industrial complexes that arose as the momentum of the naval armaments industry replaced technological innovation as the driving force of the business.[1]

This viewpoint requires some revision and qualification; as the following two chapters will demonstrate, the evolution of armaments technology remained an important feature of the industry after 1900. Bastable nevertheless highlights a number of important aspects of the industry, but to suggest that technology was no longer one of the main driving forces behind the business takes attention away from the extensive experimental work undertaken by armaments companies in the Edwardian period. As Trebilcock has asserted, 'in 1900 the armaments industry was, possibly, the most scientific of all industries,' and the largest armaments companies, Armstrong and Vickers, could spend up to £100,000 a year on experiments.[2] This was not an industry with a declining interest in developing the most advanced armaments possible. Nowhere was this more apparent than in the improvement of armour piercing projectiles, a product which demonstrates the fusion of armaments and metallurgical knowledge. Examining the period from 1900 to the Great War, this chapter will explore the development of the Heclon armour piercing (AP) projectile at Hadfields, followed by a discussion of Firth's development of their Rendable AP projectile. These case studies will demonstrate the path dependent nature of armaments technologies, the interactions between civilian and armaments research at the two companies, and the opportunities for technological spin-off. The chapter will then investigate the collaborative arrangements of the two

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[1] M. J. Bastable, *Arms and the State: Sir William Armstrong and the Remaking of British Naval Power, 1854-1914* (Aldershot, Ashgate, 2004), p.10. For a general discussion of the British market-cum-technological environment between 1870 and 1914, see J.F. Wilson, *British Business History, 1720-1994* (Manchester, Manchester University Press, 1995), pp.87-98.

[2] R.C, Trebilcock, 'A 'Special Relationship' – Government, Rearmament, and the Cordite Firms', *Economic History Review*, Vol.19, No.2 (1966), p.379.

companies to further advance AP projectiles, and examines the patent arrangements and the marketing and licensing of projectile technology by Hadfields and Firth.

Hadfields and the Development of the Heclon Armour Piercing Projectile

Robert Hadfield Senior commenced the manufacture of steel castings at Hadfields in 1872, and soon after utilised the production method to make projectiles for the first time in 1877.[3] It was later said that 'patriotically he fretted over the fact that French pre-eminence in this field posed the threat to Britain of dependence on a foreign source for a military essential.'[4] While Hadfield Senior manufactured projectiles out of patriotism, his son Robert Abbott Hadfield had an outright obsession with achieving and then maintaining the company's lead in the field of AP projectiles. It was later claimed that nothing excited him more than watching a shell penetrate an armour plate.[5] The elder Hadfield had encouraged his son to learn metallurgy and sent him on a tour of America from June to August 1882 'to introduce the young Sheffielder to the metallurgical and business world in preparation for his role as director of the family firm.'[6] Hadfield Senior even had a furnace installed at the family home, where after his return from America in 1882 Hadfield invented what would be known commercially as manganese steel. This material, known for its hard-wearing properties and toughness, demonstrated the positive contribution scientific methods could have to the development of metallurgy, and was the first major innovation in the emerging field of alloy steel production.[7] Hadfield later invented silicon steel, a material used in the development of electrical transformers, and by 1900 was recognised as one of the foremost metallurgists in the world.[8] His knowledge of

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[3] For an overview of the origins of steel casting in Sheffield, see G. Tweedale, 'Pioneering in Steel Casting: A Melter's Reminiscences, ca.1856-70s', *Journal of the Historical Metallurgy Society*, Vol.27, No.2 (1993), pp.102-109.

[4] *Steel Review,* Vol.11, July 1958, p.39.

[5] G. Tweedale, *Steel City: Entrepreneurship, Strategy, and Technology in Sheffield 1743-1993* (Oxford, Clarendon Press, 1995), pp.192-193.

[6] G. Tweedale, *Giants of Sheffield Steel* (Sheffield, Sheffield City Libraries, 1986), p.42.

[7] For an overview of the development of manganese steel, see R.A. Hadfield, *Metallurgy and its Influence on Modern Progress* (London, Chapman and Hall, 1925), Chapter 7: Manganese Steel; and G. Tweedale, 'Sir Robert Abbott Hadfield F.R.S. (1858-1940), and the Discovery of Manganese Steel', *Notes and Records of the Royal Society of London*, Vol.40, No.1 (1985), pp.63-74.

[8] For more on Hadfield's later developments, see Hadfield, Chapter 8: Silicon Steel; Tweedale, *Giants*, pp.41-48, and C.H. Desch, 'Robert Abbott Hadfield 1858-1940', *Obituary Notices of Fellows of the Royal Society*, Vol.3, No.10 (1941), pp.647-664.

how various elements altered the properties of alloy steels certainly assisted the development of AP projectiles at Hadfields.

Figure 1.1: Portrait of Sir Robert Abbott Hadfield

After the death of his father in 1888, Hadfield took over the company and imprinted his interests in both metallurgical development and armaments production on the company's strategy. In addition to being Hadfields' chairman and managing director, Hadfield was also head metallurgist and de facto head of armaments developments. From 1888 Hadfield placed a renewed emphasis on projectile development, and had received three small orders from the British Government by 1890.[9] Work on early types of AP projectiles facilitated an expansion of productive facilities for armaments, and by 1897 Hadfields had outgrown their original Hecla Works. Construction of the East Hecla Works began the same year, and once completed the Hecla Works were dedicated solely to the production of war material. The increased scale of projectile development had been facilitated by the expanding research facilities at the

[9] Sheffield Archives (SA), Hadfields Box 124, Shell and Shot For British Government 1877-1893.

company, and such was the investment in research by Hadfield, in 1900 the company's laboratory was perhaps the most advanced in the world. As Tweedale has highlighted, Hadfield regarded the laboratory as not simply a place to analyse steel, but 'as the driving force behind the whole company.'[10] In no other line of production was this seen more than the development of AP projectiles.

Robert Hadfield Senior's decision to use his company's steel casting capabilities to manufacture AP projectiles for the first time in 1877 marked not only the start of Hadfields' long association with armaments production, but also gave the projectile superiority over contemporary armour plate designs. Introduced in the early 1870s, iron armour faced with steel had superseded iron armour, thanks to the revolution in bulk steel production following the introduction of the Bessemer converter. Known as 'compound' armour, the design could not withstand attack from cast steel projectiles. The use of cast steel was the major innovation which commenced a new path of technological development with AP projectiles at Hadfields. However, their superiority over armour plate would be short lived. By the 1890s, armour plate technology had advanced more rapidly than projectiles and resulted in two new methods of hardening, both of which could withstand attack from Hadfields' cast steel projectiles.[11] The first of these was the Harvey method, developed in the US and licensed from 1891, which used water sprays to harden the armour plates after forging. Soon thereafter, the method was superseded by the development of Krupp Cemented (KC) plates, developed by the German manufacturer of the same name, which used a nickel-chromium alloy steel to provide more resistance than Harvey plates. Krupp licensed the method to other producers, with Vickers, Cammell and Brown all producing them in the Sheffield area.[12]

By 1900 the resistance of KC plates was well known, and their superiority over contemporary AP projectiles. *The Engineer* commented that:

> The great toughness of the Krupp armour, which appears to be maintained in a remarkable degree in thick plates, is no doubt partly due

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[10] G. Tweedale, 'The Business and Technology of Sheffield Steelmaking' in C. Binfield, R. Childs, R. Harper, D. Hay, D. Martin and G. Tweedale, *The History of the City of Sheffield 1843-1993 Volume 2: Society* (Sheffield, Sheffield Academic Press, 1993), p.157.

[11] For an outline of the technological war between shell and armour plate before 1900, see A.C. Marshall and H. Newbould, *The History Of Firths 1842-1918* (Sheffield, 1925), pp.60-62.

[12] See the following chapter for more details, and D. C. Oldham, *A History of Rolled Heavy Armour Plate Manufacture* (Sheffield, South Yorkshire Industrial Heritage Society, 2010), pp.2-3.

> to the presence of nickel, and partly due to the method of treatment, *so that Hadfield may be pardoned when his projectiles are defeated by such plates.*[13]

Such was the shell resistance of a KC plate, when a traditional pointed projectile was fired against the armour the projectile would either ricochet off or break up on the surface of the armour plate. The most widely researched and adopted solution to this issue was to place a soft steel cap over the pointed nose of the projectile to aid in the successful perforation of the armour. The action of the cap was outlined by *The Engineer* in 1902:

> When the projectile first strikes the plate the whole energy is delivered to the extreme point, and in most cases the latter is completely crushed out of recognition…In order to preserve the extreme point from damage so as to assist it in delivering the full energy of the projectile at the point of impact, the idea occurred of attaching to it a cap of soft, but tough, steel.[14]

By utilising a capped projectile, greater penetrative power could be achieved. The cap would absorb the initial impact upon the face of the armour, before folding away around the projectile to allow the point to successfully perforate the armour plate unimpeded.[15]

For the development of an AP projectile, there were a set of technological challenges to considered and resolved before a finished product could be presented to potential customers. What would be the ideal composition of the alloy which would make up the body of the projectile; would it be immune to the problem of spontaneous fracture, when a projectile would split and jam in the gun barrel during firing, which had plagued other projectiles; after casting how would the body of the projectile be treated to ensure the optimum performance when fired; what would be the composition of the cap and how would it be fitted to the projectile; and perhaps most paramount, how would quality control be implemented to ensure consistency among projectiles? These were important technical questions because when delivered to the British Government, one projectile out of a batch would be selected at random and test

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[13] *The Engineer*, 5 January 1900, p.21. My emphasis.
[14] *The Engineer*, 27 June 1902, p.624.
[15] Hadfield discusses the use and action of projectile caps in the *Minutes of Proceedings of the Institution of Civil Engineers* (London, 1903), p.20. For another contemporary account, see 'Modern Armour And Armour-Piercing Projectiles,' *The Engineer*, 12 April, 19 April, 26 April, and 3 May 1907.

fired as a proof. If it failed, the entire batch would be rejected. With the amount of research, development, and testing needed to comply with this list of requirements, before even being considered as an approved supplier for the British Government, it is understandable why barriers to entry into the industry were so high, and the number of suppliers so few. To understand how these technological challenges were overcome, and how they contributed to the development of capped projectiles at Hadfields, it is necessary to view a finished projectile as utilising a series of sub-innovations each designed to build on and refine the initial major innovation in advanced projectile technologies, the use of cast steel from 1877. On the development of sub-innovations, Rosenberg has suggested that 'such activities involve endless minor modifications and improvements in existing products, each of which is of small significance but which, cumulatively, are of major significance.[16] For projectiles, the 'major significance' resulting from the introduction of a number of sub-innovations was the ability to perforate KC armour.

Building on the use of cast steel, experiments with using alloy steels for AP projectiles began in the 1890s. Hadfield's knowledge of metallurgy certainly assisted his research. His experiments gave him an intimate knowledge of the properties of manganese, and knew its content had to be accurately controlled in alloy steels for projectiles. In 1897, Hadfield patented a nickel-chromium steel alloy for use with projectiles[17] which highlighted that 'this invention has reference to the manufacture, at a comparatively low cost, of cast projectiles possessing great strength and penetrative powers and specially suitable for armour piercing and like purposes.'[18] The alloy, later marketed as Hadfields' special 2/2 nickel-chromium steel, contained between 0.75% and 1% carbon, 2% nickel and 2% chromium with special importance given to keeping the manganese content below 0.3%. Hadfield's knowledge of the properties of manganese clearly assisted in the alloy's development, and he stated that 'I have found that the common accepted idea that manganese is necessary in steel is to a large extent erroneous, and in fact its presence is in many ways deleterious.'[19] Hadfield discovered that issues encountered from not monitoring

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[16] N. Rosenberg, *Exploring the Black Box* (Cambridge, Cambridge University Press, 1994), pp.14-15.
[17] British Patents 27,753/1897, 27,754/1897 and 27,755/1897.
[18] British Patent 27,754/1897, p.3.
[19] British Patent 27,754/1897, p.4.

the amount of manganese were related to the formation of manganese carbides in high carbon alloy steels with over 0.35% carbon. He recorded that:

> Manganese is in itself a very hard and brittle metal and while this in itself may not be an objection, yet I consider that in its action as a carbide of manganese when carbon is present, it is most harmful where the special qualities of hardness and toughness are requisite, as in the production of projectiles, believing that these qualities cannot be developed if manganese is present in quantity say over 0.25% to 0.3%.[20]

Furthermore, controlling the levels of manganese in the alloy helped to reduce the cost of producing AP projectiles:

> whilst it has heretofore been necessary in the production of armour piercing projectiles of hard steel to employ the very highest quality of raw material, such as Swedish pig or melting iron, I find that by making the steel free from or low in manganese as set forth, the steel may be allowed to contain a larger proportion of sulphur and phosphorous than otherwise be admissible, consequently I am able to use in the production of my projectiles cheap raw stock such as ordinary hematite pig iron, or even mixtures of ordinary pig iron and scrap steel…thus rendering available a much wider range of raw material of comparatively small cost for the production of armour piercing shell.[21]

In developing nickel-chromium alloys, Hadfield was able to apply his knowledge of metallurgical developments to the advancement of AP projectile technologies, while simultaneously reducing the cost of their production. Furthermore, Hadfield's stringent specifications regarding the composition of his alloy steels helped to provide a uniform quality and performance from the projectiles. Accuracy was paramount in the production and development of projectiles and alloy steels, two fields in which Hadfield was at the forefront in pioneering. The advance of scientific analysis and theories to steelmaking was also a clear indicator that Sheffield's rule of thumb methods had passed their heyday, though the traditional approaches and methods did not disappear overnight.[22]

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[20] British Patent 27,754/1897, p.4.
[21] British Patent 27,755/1897, p.5.
[22] Tweedale, 'Business and Technology', p.156.

By experimenting with hardening techniques to advance the performance of AP projectiles, in 1901 Hadfield further refined the alloy to benefit from the hardening effect of manganese in nickel-chromium steel. It had been found that by producing a 2/2 nickel-chromium steel with 0.8% carbon and 0.12% manganese, the manganese had a ‘powerful effect in promoting the hardening of nickel-chromium steel’ when heated to 900ºC and then cooled by a blast of air.[23] Despite being developed for use with projectiles, this refined alloy and hardening technique had a wide range of applications away from armaments:

> Besides being beneficial in the manufacture of projectiles, my [Hadfield’s] invention can be advantageously adopted in the production of other hardened steel articles of various kinds (especially castings), including *inter alia*, shoes and discs for use in ore crushing, the wearing parts of crushing machinery, rolls of various kinds, car wheels, railway wheels, cutting tools of various kinds.[24]

While this version of 2/2 nickel-chromium steel would never be widely used in the manufacture of projectiles, the technological spin-off provided the basis for further developments with established commercial lines at Hadfields. By 1905 the rock and ore crushing machinery produced by the company since the 1890s, utilising Hadfields manganese steel for the main crushing mechanisms, was using this alloy in their support frames and construction, with South Africa being a major export market before 1914.[25] From the early 1900s, a mix of commercially-focused and armaments-focused research were driving product developments at the company.

In addition to the development of Hadfields’ original 2/2 nickel-chromium steel for projectiles, Hadfield also developed a series of sub-innovations which, when utilised in combination, had the potential to produce an improved AP projectile. Multiple patents relating to advances in casting and hardening were issued from the 1890s, which show advancement from casting a projectile point up to point down, and developments in hardening different aspects of a shell body in different ways.[26] Also developed were air deflectors[27] which could be

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[23] British Patent 6,089/1901, pp.3-4.
[24] British Patent 6,089/1901, p.4.
[25] See C. Trebilcock, ‘“Spin-Off” in British Economic History: Armaments and Industry, 1760-1914’ *Economic History Review*, Vol.22, No.3 (1969), pp.474-490 for a discussion of spin-off in the British Armaments industry.
[26] See British Patents 8,971/1894, 24,453/1895, 3,543/1898, 13,670/1899, 6,091/1901.
[27] British Patent 16,901/1898.

placed over a projectile's cap to provide a smoother flight and more aerodynamic stability, and two methods of attaching caps to shells, due to Hadfield having doubts about other methods when used in practice.[28] The latter of these patents were adopted by Hadfields for the majority of its capped projectiles prior to the Great War and gave them their distinctive 'thumb marks.' Producing projectiles necessitated 'forming indentations or concavities in the projectile and pressing or forcing portions of the metal of the cap into the said indentations or concavities.'[29]

The result of this series of sub-innovations and advances over the course of a decade were two patents in 1904 in which Hadfield combined multiple developments in projectile technologies.[30] The resultant product was branded Hadfields' 'Heclon' AP projectile, and became the company's standard AP projectile design for the next 15 years. Prior to these patents there had been successful, yet inconclusive trials with capped AP projectiles. As Hadfield highlighted in the patent specifications, when used against KC plates 'armour piercing projectiles of the ordinary type, even if capped, do not give uniformly good results.'[31] The first Heclon patent of 1904 referred to a new type of heat treatment 'in a different manner to that heretofore usually practiced.'[32] The patent utilised a further refined projectile which had been developed since 1898, still a 2/2 nickel-chromium steel but with a controlled 0.6% carbon content and manganese content as low as possible, treated in such a way to provide both toughness and hardness in the body of the projectile.[33] Due to the effectiveness of this treatment, Hadfield made a bold statement in his patent application that, 'by the improved treatment it is possible to produce projectiles which, when capped, *will perforate KC armour unbroken*.'[34] Three months after the first Heclon patent, a further refinement was made to the hardening process which improved the performance of the projectile. After being annealed and formed to shape, the projectile was slowly heated to between 820ºC and 890ºC for a 6

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[28] British Patent 20,983/1898, p.3.
[29] British Patent 21,805/1898, p.2.
[30] An excellent overview of the development of projectiles prior to 1904 is provided by David Carnegie's 'The Manufacture and Efficiency of Armour-piercing projectiles' in *Minutes of Proceedings of the Institution of Civil Engineers* (London, 1903).
[31] British Patent 7,882/1904, p.3.
[32] British Patent 7,882/1904, p.3.
[33] This had been suggested at between 0.12% and 0.3% in previous patents, but not specified here.
[34] British Patent, 7,882/1904, p.4. My emphasis.

inch projectile, after which the point was cooled in oil. Furthermore, 'by the treatment described, the head or point of the projectile is rendered extremely hard, whilst the walls of the projectile and rendered remarkably tough and stiff to withstand compressive strains.'[35] When capped and tested, a 6 inch projectile was able to perforate a 6 inch KC plate.[36] The projectile cap was also redesigned for the Heclon. These were produced in mild steel and heat treated to between 950ºC and 1100ºC. To ensure uniform results Hadfield had found it advantageous to stamp the caps between shaped dies. The problem of spontaneous fracture which had been an issue with older projectiles was also solved by the low percentage of manganese used in the 2/2 nickel-chromium steel. In 1918 it was remarked that Hadfields' Heclon projectiles were immune to spontaneous fracture, and that none had ever been reported in practice.[37] After a series of initial trials in 1902 both in the UK and abroad,[38] followed by successful British Government trials starting in 1904,[39] the first large order for Heclon AP projectiles was placed in June 1904 for 6,000 6 inch projectiles.[40] The Heclon patents and methods could be applied to projectiles from 6 to 15 inch calibre, allowing the production method to fulfil the British Government's entire AP projectile requirements. Following the first order, by the end of 1905 the company had received orders for in excess of 14,000 Heclon AP shells.[41]

In creating the Heclon, Hadfield was able to produce an advanced AP projectile with its origins in the major innovation of utilising cast steel for the projectile body. This was supplemented by a series of sub-innovations designed to solve a string of issues which had plagued AP projectiles in use against KC plates. The resultant Heclon patents utilised a series of these innovations in combination, highlighting the path dependent nature of projectile development at the company. Furthermore, the Heclon's development was strongly influenced by Hadfield's commercial metallurgical knowledge, assisted by the trial and error approach of rule of thumb methods to experimentation. Through the research undertaken into the effects of various elements on the composition of alloy steels, armaments development provided the basis for a series of new

[35] British Patent 15,219/1904, p.3.
[36] British Patent 15,219/1904, p.5.
[37] SA, Hadfields Box 59, Patents and Royalties, January 1918, p.22.
[38] *The Engineer*, 27 June 1902, p.624.
[39] Sheffield City Library (SCL), Hadfields Steel Foundry Co. Ltd. Book, 1905, pp.25-33; *The Engineer*, January 5th 1906, p.20.
[40] SA, Hadfields Volume 151, Projectile Orders Number 1, p.152, 21 June 1904.
[41] SA, Hadfields Volume 151, Projectile Orders Number 1.

commercial production lines at Hadfields, influenced by the spin-off of new metallurgical knowledge from armaments research.

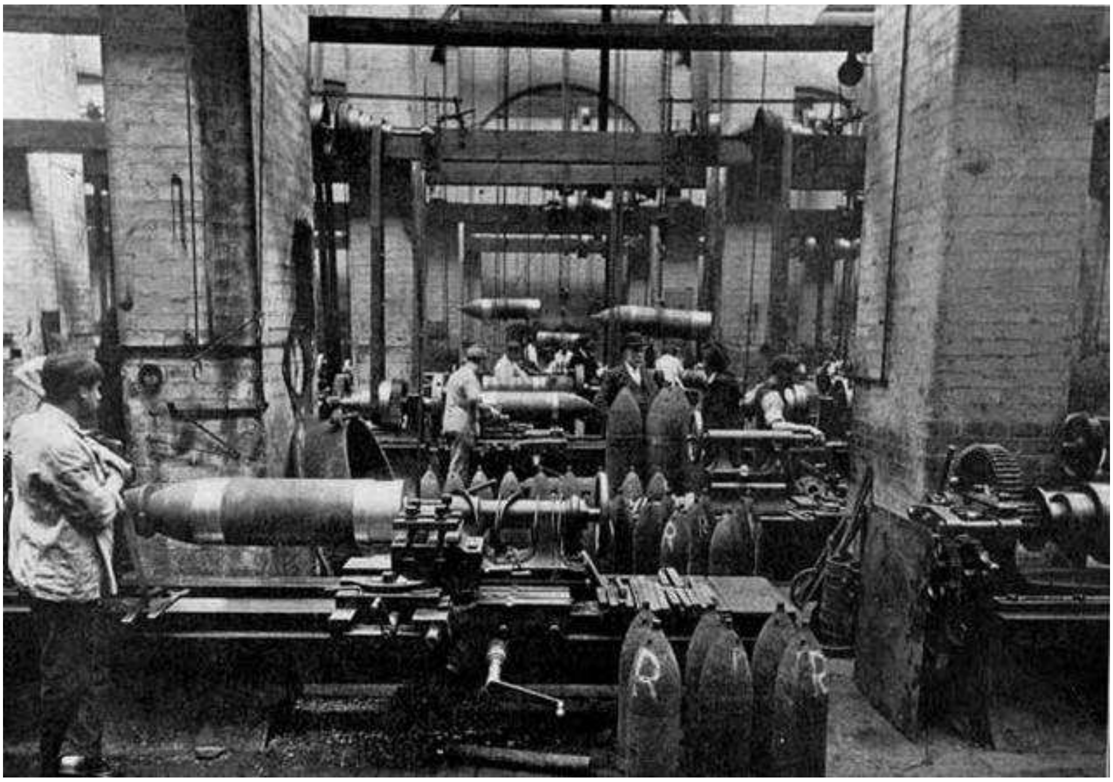

Figure 1.2: Interior of Hadfields' Hecla Works, 1905

However, the development of the Heclon was not without significant cost to the company. In 1905, Hadfields acknowledged that they were spending large amounts on their armaments research and development:

> The money that is sometimes spent – first in laboratory research, and afterwards in experiments on full scale – represents very large sums indeed, many thousands of pounds often being devoted to the working out of a single detail, or perhaps simply to arrive at a negative result, and the directors of manufacturing establishments, having spent large sums of money upon gathering knowledge, look on data thus acquired as one of the assets of the business.[42]

Two conclusions can be drawn from this statement. Firstly, in the process of developing sub-innovations and refinements dead-ends would inevitably be reached that are not recorded in the patent records. Secondly, all of the research and development undertaken at Hadfields created knowledge which

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[42] SCL, *Industries of Sheffield and District*, 1905, p.45.

was retained and valued by the company, regardless of a positive or negative outcome. This information could be tacit knowledge related to metallurgy, retained by Hadfield and the staff employed at the company's research laboratory and potentially important for future armaments or commercial developments.[43] Nevertheless, Hadfields represents only one technological path related to projectiles in Sheffield, with Firth involved in the development of a competing, but equally successful outcome.

Firth and the Rendable Armour Piercing Projectile

As Metcalfe suggests, 'no two firms are expected to innovate in identical fashion,' and the development of projectiles was no exception.[44] Firth had begun producing armaments during the Crimean War, with the manufacture of solid round shot. Thereafter, the company had 'taken a leading part in all the succeeding stages' of projectile manufacture.[45] Firth were also one of the pioneers of high speed steels in the 1890s with their 'Speedicut' type, essential in the machining of hardened material such as armour and projectiles.[46] In contrast to Hadfields, Firth's projectile developments were based on the major innovation of utilising forged steel from the 1860s, rather than cast steel. By the 1880s, their projectile capacity was concentrated in part of the Norfolk Works known as the Gun Works, a highly specialised forging plant containing interchangeable technology, the same equipment being used for both commercial and armaments production.[47] This ability to utilise their works for two different types of product suggests that Firth had a flexible specialisation with forging technology, and were attuned to the dynamic capabilities of their works.[48] Flexible specialisation facilitated the Gun Works production of gun

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[43] For a discussion of tacit knowledge, see G.M. Hodgson, *Economics and Utopia: Why the Learning Economy is Not the End of History* (London, Routledge, 1999), pp.46-9.
[44] S. Metcalfe, 'Technology Systems and Technology Policy in an Evolutionary Framework' in D. Archibugi and J. Michie, *Technology, Globalisation and Economic Performance* (Cambridge, Cambridge University Press, 1997), p.271.
[45] Marshall and Newbould, p.60.
[46] High speed steels are cited by Trebilcock as a key area of spin-off from armaments research and development to civilian industry. See Trebilcock, 'Spin-Off' pp.483-4. On the development of high speed steels in Sheffield, see G. Tweedale, *Steel City: Entrepreneurship, Strategy, and Technology in Sheffield 1743-1993,* (Oxford, Clarendon Press, 1995), pp.113-9.
[47] Firth's Gun Works were profiled in *The Engineer*, 29 January 1898, p.53.
[48] Firth were somewhat more attuned to the dynamic capabilities of their productive facilities. On dynamic capabilities see D. Teece, and G. Pisano, 'The Dynamic Capabilities of Firms: An Introduction', *Institutional and Corporate Change*, Vol.3, No.3 (1994), pp.537-556. Eason has also suggested that Firth's armaments business was developed to allow a flexible specialisation between military and civilian production. See M. Eason, *Business, Training and Education:*

forgings, air vessels and marine shafting in addition to projectiles, as shown in Figure 1.3.

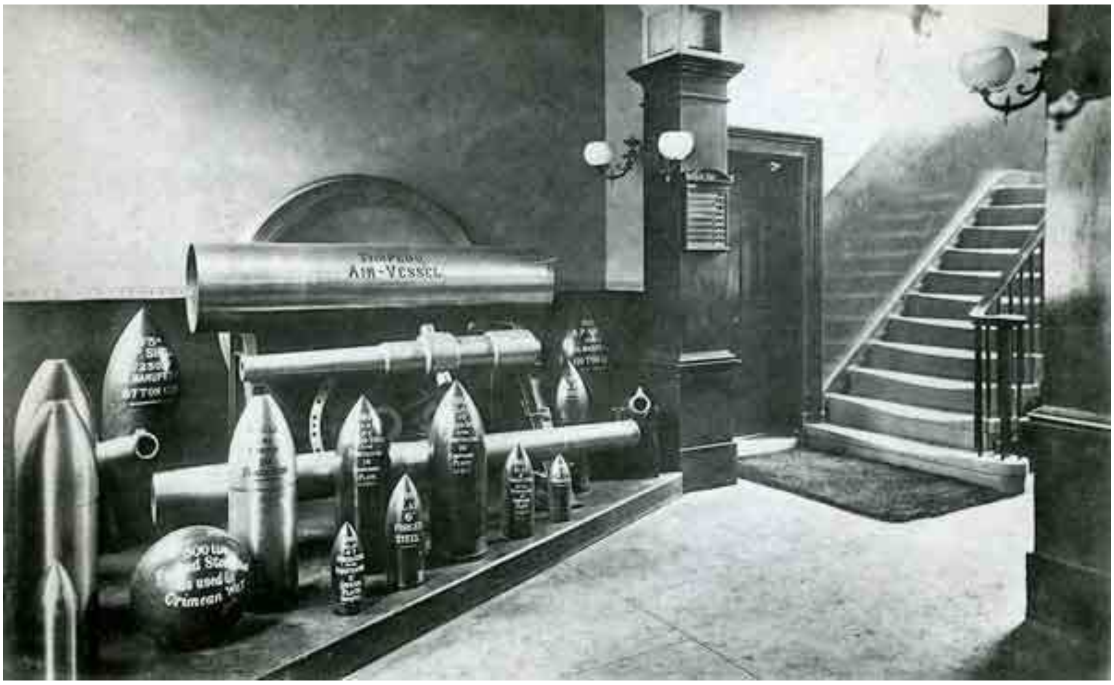

Figure 1.3: The entrance to the offices of Firth's Norfolk Works, about 1906. The display is of all the products the Gun Works had produced since the Crimean War.

At the centre of Firth's projectile research and development was James Rossiter Hoyle, who joined the company in 1881 and became the first member of their board of directors not from the Firth family in 1893. Hoyle was unique in pre-1914 armaments technological development, having never served in the military or undertaken any metallurgical training his contemporaries all having one or both of these experiences prior to commencing research and development work with armaments. His background was as a practical engineer, and he had developed a keen interest in gun and projectile manufacture before joining Firth. Hoyle's experience had been gained working in both England and France as an engineer and salesman. His knowledge of the French language and armaments production gained the attention of Charles Henry Firth, who offered him a position in 1881 when Firth had secured a large contract for gun forgings with the French Government. Soon thereafter he was made manager of the Gun Works, beginning a 45 year association with the

Sheffield circa 1880-1940, Unpublished PhD Thesis, Sheffield Hallam University (1997), p.86; P. Scranton, 'Diversity in Diversity: Flexible Production and American Industrialization, 1880-1930', *Business History Review*, Vol.65, No.1. (1991), pp.27-90.

company.[49] Hoyle, as we shall see, was to be a key figure in projectile innovation at Firth for three decades.

After the introduction of KC Armour in the 1890s Firth, like Hadfields, began exploring ways to refine their AP projectile designs. One design explored by the company was a type of AP projectile designed to carry a bursting charge, which was introduced in 1900.[50] In trials, however, the uncapped projectile was unable to give consistent results and frequently exploded before perforating the armour plate. Firth thereafter opted to continue development of capped AP projectiles, a product that they had been producing since 1894. A key element of developments at Firth was a mix of utilising in-house innovation and the use of outside licenses to supplement their research and development activities. For instance, in 1886 Firth researched the production of chrome-steel shot, and also bought the rights to making similar shells from the Firminy Company of St. Etienne in France.[51] From May 1900, Firth were granted a licence from Hadfields to use their patents and processes to manufacture 2/2 nickel-chromium steel for use with projectiles. The royalties involved were small; an order Firth obtained for 6,000 6 inch AP projectiles required a payment of £1,200 to Hadfields, or 4 shillings per shell.[52] The main difference between the two companies was that Hadfields commenced the production process by casting the steel, while Firth produced steel ingots and then forged the shells to the required shape.[53]

By utilising Hadfields' patents for projectile steels, Firth reduced the number of technological challenges faced to refine the performance of their AP projectiles. As previously outlined with Hadfields, the remaining challenges Firth had to overcome were related to how the cap would be fitted to the body of the projectile, and the design of the cap and head of the projectile. A unique feature of forged projectiles was related to the distribution of steel throughout the body of the shell. Once again, to understand a finished projectile at Firth, the solutions to these technological challenges should be viewed as sub-innovations utilised in conjunction with the major innovation of using forged

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[49] The information about James Rossiter Hoyle is from his obituary in *The Engineer*, 19 March 1926.
[50] SCL, *John Brown and Company Limited*, 1903, p.64.
[51] Marshall and Newbould, p.60.
[52] SA, X306/2/5/4/1, Bernard Firth to Robert Hadfield, 24 May 1900.
[53] SA, X306/2/5/4/1, Process of Manufacture of Projectiles, 11 August 1915. This is the only source available which outlines Firth's method of projectile manufacture.

steel at the company. While these were common problems faced by the projectile manufacturers, each company explored different solutions and built on different major innovations to overcome them. What can be observed are two different instances of path-dependent research, originating from the differing core competences of Firth and Hadfields. The evolution of armaments technology was also unique to each company and research team involved.

Hoyle's work began in 1902 with an updated projectile head and cap shape which became the standard design for Firth's shells for the next six years. Intended to prevent damage to the projectile head at the moment of impact with an armour plate, the design flattened the point of the projectile and covered it with a cap to aid with perforation. The patent emphasised that:

> The truncated cone of the head gives better results against hard faced plates than the pointed head generally used, whilst the cap provided has the double object of reducing the shock on impact of the projectile against the plate and also retains the present form of head for accurate shooting.[54]

This design change was followed in 1903 by a revised shape for the base of the projectile. Previously projectiles made by Firth had a flat bottom which in the new design was replaced by a grooved bottom, allowing for the steel saved to be distributed to the head of the projectile. Hoyle had discovered that by increasing the steel content in the head of the projectile its armour piercing properties were improved when fired against KC armour.[55] The final aspect of Hoyle's research was an updated method of attaching caps to the projectiles. This involved the cutting of three grooves in the head of the projectile and cap, the grooves being filled with white metal to secure the cap in place.[56] These sub-innovations, used in combination with Hadfields' shell treatment process, and building on the use of forged steel at the company, created an AP projectile which could defeat KC armour. This again demonstrates the path-dependent evolution of projectile technology, and a different process of innovation compared to Hadfields.[57] Known as the Firth Rendable AP projectile, these

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[54] British Patent 28,376/1902, p.2.
[55] British Patent 18,414/1903, p.2.
[56] British Patent 8,037/1904, p.2.
[57] For a discussion of technological path dependence, see Rosenberg, *Black Box*, Chapter 1: 'Path-dependent aspects of technological change.'

were ordered in 6, 7.5 and 9.2 inch calibres soon after their introduction in 1904, and were sent for testing at the Royal Laboratories in early 1906.[58]

The solutions devised by Hoyle to refine the performance of AP projectiles were based on the practical manipulation of steel rather than the application of science and metallurgical knowledge to their advancement, utilising rule of thumb methods in contrast to the integration of alloy steel experimentation by Hadfield. This was undoubtedly a result of Hoyle's background as a practical engineer, utilising his knowledge of forging steel from his tenure as manager at Firth's Gun Works. While devoid of any metallurgical developments related to alloy steel, the result of the Rendable's development was an AP projectile whose performance could rival Hadfields' Heclon AP projectile. Hoyle may have been less prolific than Hadfield with patenting and advancing the science of alloy steels, but the result was a second AP projectile design which could defeat KC armour, developed in close proximity in the same industrial district.

The company's approach to AP projectile research, using a mix of in-house developments and outside technology, gave Firth access to a second AP projectile designed by their American subsidiary, confusingly also known as the Rendable. In 1896 Firth had obtained the controlling interest in the Wheeler Sterling Steel Company, based in Pittsburgh, Pennsylvania to manufacture projectiles and tool steel in the United States, renaming it the Firth-Sterling Steel Company. When company manager Charles Yandes Wheeler died in 1899, Lewis Firth was appointed President of the company and Firth increased their investment to £250,000, two-thirds of the overall capital of Firth-Sterling.[59] In early 1900 the transfer of all the assets, contracts and patents from the former company was complete, which included a type of AP projectile invented by Charles Van Cise Wheeler, son of the former company manager.[60] This design had been licensed to Armstrong in the 1890s.[61] Wheeler was works manager at Firth-Sterling in Pittsburgh, and along with works metallurgist Alexander George McKenna continued research into AP projectiles. The result

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[58] *The Engineer*, 5 January 1906, p.20.
[59] G. Tweedale, *Sheffield Steel and America: A Century of Commercial and Technological Interdependence 1830-1930* (Cambridge, Cambridge University Press, 1987), pp.94-95.
[60] Marshall and Newbould, pp.71-2., SA, X306/1/2/3/1/2, Firth's Directors Meeting Minutes, 31 January 1900.
[61] *The Engineer*, 7 January 1898, p.18.

was their 'Rendable Shell' in 1902, a design developed at the same time and with a number of similarities to the Firth Rendable AP projectile.

The Firth-Sterling Rendable Shell was covered by three American patents. The first outlined a new blunted nose for the projectile, thinner walls compared to contemporary designs to allow for more explosive to be utilised, and a proposal for the replacement of both common and AP projectiles with a single design.[62] While AP projectiles were specialised for the attack of armour, common shells were used against a much wider range of targets, and generally contained more explosives than AP projectiles. This standardisation would have made production simpler and could have brought more orders for the projectile. The second incorporated a revised design to prevent the breaking of the base and subsequent cracking of the walls of the projectile upon impact with an armour plate, which could prevent successful detonation.[63] The final aspect of the Firth-Sterling Rendable shell was the cap; a square steel version similar in design to the one developed at Firth, with the same grooved and soldered method of attachment.[64] Overall, the Firth-Sterling Rendable patents were comparable to those developed for Firth's Rendable AP projectiles and show a similarity in design. In some cases, such as the profile of the cap, Firth were ahead with a similar design by at least a year, Hoyle later stating that 'a form of head similar to the one which [Firth-Sterling] claim as their own was designed here as far back as June 1901.'[65] Nevertheless, Firth-Sterling remained adamant that their design was superior to that of Firth and in late 1903 suggested to their parent company they purchase the sole rights to the process in the UK.[66] Firth were reluctant; the Firth-Sterling design was unproven with large calibre projectiles, and their own comparable design could be used free of royalties. In March 1904, Firth-Sterling's offer for the sale of their Rendable shell licence was $60,000 (£12,320). Firth's board declined, proposing a royalty on each shell sold under the process for a limited time instead.[67] Four weeks later the Firth-Sterling offer had fallen to $10,000 (£2,053) and a 7½% commission on the sale of Rendable shells, which Firth also rejected. Their counter offer

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[62] US Patent 721,487, 1902.
[63] US Patent 725,385, 1903.
[64] British Patent 19,686/1903. This is the same as US Patent 748,827 of 1903.
[65] SA, X306/1/2/3/1/3, Firth's Directors Meeting Minutes, 29 March 1904.
[66] SA, X306/1/2/3/1/3, Firth's Directors Meeting Minutes, 22 December 1903.
[67] SA, X306/1/2/3/1/3, Firth's Directors Meeting Minutes, 29 March 1904.

was a maximum of 2½% commission.[68] A letter received from Firth-Sterling's American counsel, Harold Binney, as part of the negotiation attempted to aggrandise the American Patent system over the British, and aspects of the projectile's design and performance:

> The ingenuity displayed by the inventors in their hypothetical deduction and experiments leading up to their discovery of the surprising fact that elongating the nose of the projectile and at the same time blunting its tip facilitates, instead of impeding, penetration and also increases the strength of the point, might be most naturally lost sight of in reading the simple terms of the patent.[69]

Firth were not swayed and stuck with their offer. When a reply was not received by March 1905 from Firth-Sterling, the offer was withdrawn.[70] To circumvent this, Firth-Sterling entered into negotiations with other British projectile manufacturers to licence their patents, but encountered obstacles. At a trial in Washington during November 1905, two Firth-Sterling Rendable projectiles broke up on the face of the test armour, while two Firth Rendable AP projectiles passed through without any issues. Following this development, the President of Firth-Sterling Lewis Firth suggested that 'the time had come for an absolute interchange of processes and experiences between the two Companies.' As the directors of Firth observed in 1906, 'hitherto all discussions I had had with them in reference to projectiles had been carried on by them on the assumption that the process of [Firth-Sterling] was better than [Firth], but the above mentioned trials had altered that position'.[71] A draft agreement between the two companies was produced in February 1906, signed for commencement at the beginning of 1907. The agreement stated that the two companies would engage in 'the unconditional exchange of information regarding the manufacture of hardened projectiles.' Firth also gave Firth-Sterling information on how to produce gun forgings, and would draw a royalty of 2½ percent on all projectile sales at Firth-Sterling for 10½ years thereafter. Essentially, Firth gained access to all of Firth-Sterling's patents without having to pay any royalties.[72] These negotiations

[68] SA, X306/1/2/3/1/3, Firth's Directors Meeting Minutes, 26 April 1904, 27 September 1904.
[69] SA, X306/1/2/3/2/23, Firth's Directors Meeting Papers, 27 September 1904.
[70] SA, X306/1/2/3/1/3, Firth's Directors Meeting Minutes, 1 March 1905.
[71] SA, X306/1/2/3/2/44, Firth's Directors Meeting Papers, 31 July 1906.
[72] SA, X306/1/2/3/2/44, Firth's Directors Meeting Papers, 30 October 1906. For Firth-Sterling patents beyond 1903, see US Patents 815,992, 841,753, 875,023, 893,963, 950,586, 963,489 and 968,012.

demonstrate how Firth-Sterling, a subsidiary of Firth nonetheless, perhaps believed they had more power over their parent company than in reality. It also raises questions regarding the managerial cohesion of the two companies, and the effectiveness of control exercised from Sheffield via Lewis Firth. With the outcome in Firth's favour, no further disputes between the two arose. Later the same year, the Firth-Sterling business split in half, the projectile business moving to Washington under the name of the Washington Steel and Ordnance Company and the Firth-Sterling company remaining in Pittsburgh. Firth retained their majority ownership of each, and Lewis Firth remained President of both companies.[73] Overall, by 1907 Firth had undoubtedly established themselves as a technological leader in the manufacture of AP projectiles. Their next development would cement this position, and bring them into direct conflict with Hadfields over patent rights.

Dispute and Collaboration: Competition in Projectile Designs

Following the introduction of the Heclon and the Rendable AP projectiles, research continued unabated at both companies in a quest to further refine and advance their projectile designs. A patent from Hadfield in 1907 outlined an advanced long-range cap which claimed that 'not only is the efficiency of the caps improved but also the flight of the shells or projectiles with which they are employed.'[74] The cap was designed to fit closely over the pointed portion of a projectile and be low in weight. In the case of a 12 inch projectile the cap would be 25 pounds, compared with over 85 pounds for other 12 inch projectiles fitted with a much larger cap with a longer protrusion away from the point of the projectile. This advance allowed the projectile to be more aerodynamic during flight, have longer range, and carry a bursting charge. The design was fitted to a common pointed shell with a bursting charge, and became known as Hadfields' 'Eron' shell. Introduced in 1908 by the British Government, the Eron was a common pointed capped (CPC) projectile with armour-piercing capabilities. At trials it had been found that a 12 inch Eron shell could fully perforate a 9 inch KC plate.[75] This was a capability far beyond what was expected of contemporary CPC projectiles. An updated version of the Eron was introduced

[73] Tweedale, *America*, p.95.
[74] British Patent 19,104/1907, p.2.
[75] SA, Hadfields Box 67, Eron Shell Publicity Photo, 1908.

in 1914 in response to an updated Admiralty specification which requested a CPC projectile which could perforate an armour plate of equal thickness to its calibre. Hadfields initially had difficulty with the request, and ultimately used a 'set-back' cap design which they had patented in 1912.[76] The set-back cap design, positioned closer to the point of the projectile, reduced the time between the impact of the cap and the impact of the projectile against an armour plate. With previous designs, it was found that when:

> a projectile fitted with such a cap strikes an armour plate, either normally or obliquely, the cap is liable to be shifted in position relatively to the projectile before the critical moment when the point of the projectile comes into contact with the plate with the result that the projectile is liable to be ineffective.[77]

The set-back cap design was one of several which Hadfield had designed and patented as part of his projectile research, many of which were put aside for future use, though the majority were never used commercially.

Nevertheless, Hadfield was very protective of his patents, striving to retain an exclusive command over the commercial rights to his projectile designs in the UK. As other manufacturers and inventors across the world began to produce cap designs, such as Krupp, Vickers, and Armstrong, there remained the possibility that disputes could arise regarding similarities in patents and designs. Hadfield's strategy was to avoid patent disputes entering legal proceedings, and therefore limit the risk of loosing control of what could potentially be a useful design for future specifications, as the set-back cap design proved. Purchasing the rights to designs for use in the UK, and licensing agreements were used for this purpose. During one of his trips to the US, Hadfield discovered a potential patent dispute with Cleland Davis, an inventor and US Navy officer who had patented a contour cap in the UK in 1908 which pre-dated one of Hadfield's own patents of a similar design. Hadfield quickly entered into an agreement with Davis, who assigned the patent rights to Hadfields for $250, along with all of the preliminary data and information he had generated. Hadfield wrote to Alexander Jack, one of Hadfields' directors, the day the agreement was signed, expressing his reasons for avoiding a legal dispute. 'I thought it was worth while,' Hadfield concluded, to risk 'a small sum'

[76] SA, Hadfields Box 59, Patents and Royalties, January 1918, p. 18.
[77] British Patent 15,595/1912, p.3.

to ensure that 'we shall be in a stronger position by having both patents under our control.'[78] Closer to home, however, developments at Firth would bring the two companies into dispute over the similarity of their designs and patents.

At Firth from 1908 Hoyle began working with Major Harry Bland Strange to form a research team which could draw on knowledge of projectile manufacture, and their practical use in the Army. Strange was born in 1864 into a military family of Scottish descent. It was said that every male member of his family had been part of the military under the British crown for some 150 years, and his father had been a General with the Royal Canadian Artillery. Strange had been trained at the Royal Military College at Kingston in Canada, after which he surveyed Western Canada for two years. In 1885 he accepted a commission with the Royal Artillery, where he remained until his retirement in February of 1907. During his time with the Royal Artillery, Strange completed the Fire-Masters course in 1889 and served in the Royal Ordnance Corps, where his interest in ballistics and projectiles developed [79] After retirement from the military, Strange became a manager at Firth in the Gun Works, and was given a directorship in 1909. The Hoyle-Strange team made an important development in 1908 with the introduction of their 'hollow cap' design. Writing in the 1920s, Brassey's Naval Annual summarised the design:

> It was Colonel Strang [sic], of Messrs Firths, who, in 1908, first altered the distribution of the mass of the cap to improve its efficiency. This he did by moving the material downwards towards the shell, leaving but little thickness in front of the point. In order to maintain the original external contour of the head for the purpose of flight, he found it necessary to fit a thin-plate deflector to complete the point, and what is now commonly known as the 'Hollow Cap' resulted.[80]

This design altered the form of the cap to reduce its weight and facilitate a better flight after firing.[81] After successful British trials between July and October 1908, the hollow cap was tested in Italy, Norway, Sweden, Germany, France

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[78] SA, Hadfields Box 67, Robert Hadfield to Alexander George Mackenzie Jack, 10 May 1909.
[79] The information about Strange's military career is derived from his obituary in the *Royal Military College of Canada's Class of 1937 Review Yearbook,* p.115.
[80] SCL, *The Evolution of the Modern AP Projectile,* 1924, p.8. After the Great War Major Strange reverted to the original Scottish spelling of his surname, dropping the 'e' to become Strang.
[81] On the hollow cap, see British Patent 6,942/1908.

and Austria before the end of 1911.[82] Following the initial hollow cap patent, Hoyle and Strange continued to refine the design, resulting in a further five patents, one in collaboration with Tolmie John Tresidder of Brown, which incrementally improved their performance.[83]

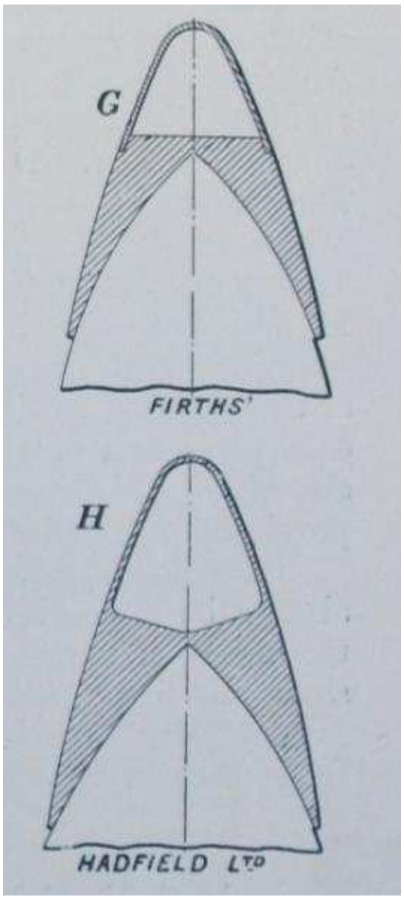

Figure 1.4: Firth's and Hadfields' Hollow Cap designs, c.1910. Taken from SCL, *The Evolution of the Modern AP Projectile,* 1924, p.7. Note the difference in Hadfields single piece and Firth's two piece designs.

However, the initial design drew the company into a patent dispute with Hadfields. While the two had produced AP projectiles for the British Government for years before, their research and designs had remained mutually exclusive. In 1908, Hadfield had also been experimenting with what he called 'false' and 'chambered' cap designs, similar to the hollow cap design from Firth.[84] The main difference between the two was that Firth's design was made from two pieces of steel, while Hadfields was made of a single piece (See Figure 1.4)., though their similarity in appearance and the close application of

[82] SA, X306/2/3/2/3, Firth Agreements with Harry Bland Strange, 1913-1918.
[83] See British Patents 17,453/1908, 10,937/1909, 28,032/1911, 10,991/1913 and 10,990/1913.
[84] See British Patents 2,817/1908 and 8,105/1908 for Hadfields' designs, 6,942/1908 and 17,453/1908 for Firth's designs.

their patents drew the two companies into commencing legal proceedings.[85] The first patent from Hadfields and the first from Firth were just 50 days apart, undoubtedly showing that the two companies were working on the same design at approximately the same time. The significance of this cannot be overstated. The Gun Works and Hecla Works were barely a mile apart in the same industrial district and home to two research teams who, working behind closed doors in the strictest secrecy, had devised two near identical projectile cap designs and sought to patent their inventions within weeks of each other.

While their legal dispute began, due to the high cost and time involved in undertaking the proceedings it was soon realised that collaboration rather than conflict was the most sensible option.[86] The two companies came to an arrangement in 1910 to revoke their patent claims and entered into a licensing agreement whereby each company would share their patents and research with the other to allow them both to produce the most advanced capped AP projectiles possible. Small royalties were paid on items manufactured under the terms of the agreement, a rate of one shilling per inch in diameter of every projectile or cap produced. To ensure that their agreement did not quickly become redundant due to rapid technological developments in the industry, the two also agreed to share any new patents related to capped projectiles after 1910. In essence, any technological advances either company developed or acquired would be shared with the other in a form of automatic cross-licensing.[87] The agreement was set to last for twelve years.[88] There are certainly overriding collusive elements to this agreement, as both companies could now potentially produce AP projectiles with equal performance. As a result, neither company had a technological advantage over the other in this line of work, ensuring that both retained their position at the forefront of capped projectile development. A key part of the agreement was the sole rights provided to Firth to licence the hollow cap design to other projectile

[85] Merges and Nelson suggest that such examples are not happenstance, and suggest that ‘Advances in science that point clearly to likely applications generate ‘races’. See R.P. Merges and R.R. Nelson, ‘On Limiting or Encouraging Rivalry in Technical Progress: The Effect of Patent Scope Decisions’, *Journal of Economic Behaviour and Organization*, Vol.25, No.1 (1994), p.18.
[86] For an example of a costly and time consuming patent dispute, see S. Arapostathis, ‘Meters, Patents and Expertise(s): Knowledge Networks in the Electric Meters Industry: 1880-1914’, *Studies in History and Philosophy of Science*, Vol.44, No.2 (2013), pp.234-246.
[87] Merges and Nelson, Technical Progress, p.21.
[88] SA, Hadfields Box 67, Agreement between Hadfields and Firths 1910, August 26th 1910.

manufacturers, and in turn pay Strange a commission on any profits gained. By the end of 1913, £2,321 had been paid to him in addition to his directors fees, one third of the profits made on licensing the hollow cap. The same year, Strange signed an agreement with Firth in which the company agreed to use any projectile patents Strange would develop or come into possession of, and pay him 25% of any profits made from future licences agreements[89] This was a lucrative proposition to the inventor, and an incentive to continue his research into projectile improvements.

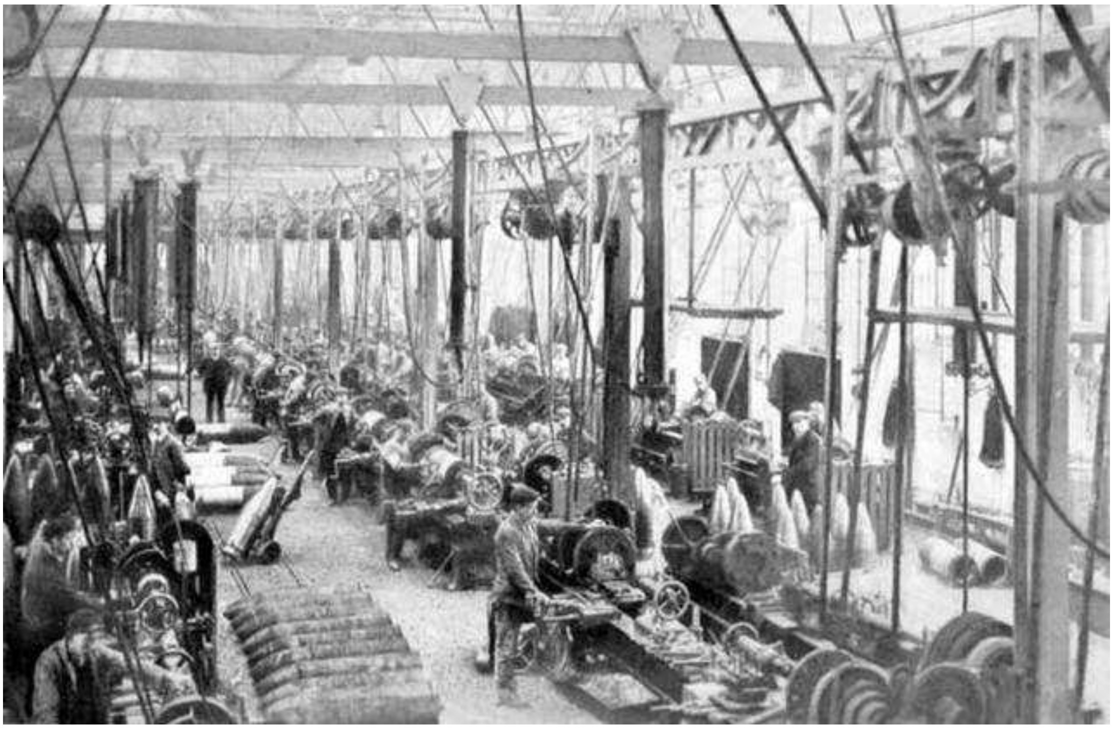

Figure 1.5: Firth's Shell Shop 1912.

One of the key issues for AP projectiles before the Great War was their inability to consistently perforate armour at oblique angles. This was known to the two producers, Firth even acknowledging in 1912 the deficiency in their marketing materials, stating that their projectiles 'are guaranteed to penetrate a full calibre of Krupp Cemented armour, provided they strike it normal [at a right angle] to the surface.'[90] This deficiency was also known to the Admiralty. After extensive experiments in 1910, John Jellicoe, then Controller of Naval Armaments, had asked the Ordnance Board to 'produce an armour-piercing shell that would perforate armour at oblique impact and go on in a fit state for

[89] SA, X306/2/3/2/3, Firth Agreements with Harry Bland Strange, 1913-1918.
[90] SCL, *Thomas Firth and Sons*, *Projectiles Charged and Ready for Firing*, 1912.

bursting.'[91] When Jellicoe went to sea two months later no one pressed the matter, and when he returned as Second Sea Lord he was no longer associated with their procurement.[92] Nevertheless, with full knowledge of the issue Hadfields and Firth began to develop caps in Sheffield for oblique attack from 1912.

Firth had previously experimented with oblique attack from their works at Riga, where the Russian Government had ordered projectiles in 1909 capable of a 20° attack to the normal against thin armour. Firth had fulfilled this requirement, 'a considerable time before such a feature was introduced into the specifications for supplies to our own country.'[93] Reflecting on their pre-war projectile development in the 1930s, it was said that 'On many occasions the experience gained in the execution of contracts for foreign Governments has led to the introduction of improvements in the shell supplies for our own Government.'[94] This was certainly the case for oblique attack. Developing their hollow cap design further, Hoyle and Strange patented a new design which incorporated a second, supplementary cap ahead of the main cap, which aided oblique attack. Upon impact in 'an oblique direction' the supplementary cap was forced 'backwards but is also displaced so that it gives most support to that side of the projectile which is remote from the armour plate.'[95]The design was further refined in two patents issued in 1914.[96] Hadfield's first design for oblique attack was the Nick Cap in 1912, and featured an annular groove around the entire cap, to prevent the projectile from sliding off the armour plate during attack, and allow the projectile to completely perforate the armour plate unimpeded.[97] The Nick Cap was superseded in 1913 by the Angelera Cap which introduced a flattened nose for more effective perforation during oblique attack. Importantly, the Angelera patent replaced the use of soft steel caps with hardened caps made of nickel-chromium steel which was heat treated. This development drew

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[91] A.J. Marder, *From the Dreadnought to Scapa Flow Volume 1: The Road to War 1904-1914* (Oxford, Oxford University Press, 1961), p.417.
[92] Marder, pp.417-8.
[93] The National Archives (TNA), T181/68, Firth Brown Evidence to Royal Commission on Arms Production, 2 October 1935.
[94] TNA, T181/68, Firth Brown Evidence to Royal Commission on Arms Production, 2 October 1935.
[95] British Patent 17,600/1913, p.2. The patent makes direct reference to the cap being 'of the type such for example is described in our British Patent Specification No. 6,942 of 1908.' This was the original hollow cap patent.
[96] British Patent 8,875/1914, 8,876/1914
[97] British Patent 21,903/1912, p.3. Tweedale also highlights the development of the Nick Cap in *Steel City*, pp.102-3.

upon the metallurgical research undertaken to produce the Heclon in 1904. In experiments a cap with 0.34% carbon, 3.86% nickel and 1.78% chromium produced good results.[98] A Heclon AP projectile fitted with an Angelera cap was successfully tested at Shoeburyness in late 1913 at an angle of 15º, followed by tests of Firth's oblique caps in 1913-14 with equally positive results.[99] Backed by these outcomes, Hadfields and Firth promoted the oblique projectile to the Admiralty with little success, the Navy choosing not to use the updated design before the War.[100] The two companies had attempted to dictate to the British Government what their future requirement was and each commenced a research program for oblique projectiles without an obvious home market or immediate financial reward.[101]

The development of the Eron CPC projectile and the hollow and oblique cap designs further demonstrate the use of sub-innovations to refine the performance of projectiles at each company. These incremental improvements were made in an environment of open-ended experimentation. After the introduction of the Heclon and Rendable, instead of working to a design specification outlined by the Government, the two companies researched improvements they believed would refine their projectiles ahead of specifications from their home buyers. This method of technological innovation was risky. Without knowing what future demands would be from the Government, each company knew their investment in new versions of their projectiles might never be rewarded. Nevertheless, the companies viewed these designs as in 'reserve' if they were ever needed, as Hadfields found with their second version of the Eron. By having designs in reserve, they could potentially reduce the amount of time between an initial request for a new technology and its successful delivery, provided the companies had accurately predicted what future demand was. The examples of Hadfields and Firth also demonstrate how path-dependent projectile research was facilitated by continuity in the constitution of the research teams. Hadfield and the team of Hoyle and Strange could build on the knowledge they developed and experimental data collected to work towards success, and continue to work with a core design based on a

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[98] British Patent 10,607/1913, p.7.
[99] SCL, *The Evolution of the Modern AP Projectile,* 1924, p.9.
[100] SCL, *The Evolution of the Modern AP Projectile,* 1924, p.8.
[101] R.R. Nelson, 'Why Do Firms Differ, and How Does it Matter?' *Strategic Management Journal*, Vol.12 (1991), p.70. Nelson stresses that 'Firms who have made the right bets do well.'

major innovation. This continuity led to dozens of improvements and patents, and the origin of two of the most used AP projectiles designs of their day in Sheffield. To further illustrate the importance of continuity in the success of innovation, we can contrast Hadfields and Firth to Cammell, whose research on projectiles was led by three different teams before the Great War and performed less successfully.

The first team at Cammell, Frederick Fairholme and Joseph Fletcher, from 1902 worked on a process of rolling heated projectiles to improve their toughness and provide more resistance when striking an armour plate.[102] This was followed in 1903 by a new method of casting projectiles, and a new design in which the nose and cap of the projectile were screwed onto the body, which had a solid base.[103] In addition to the designs perfected by Firth and Hadfields, the Cammell design had the potential to be a third method of producing AP projectiles to defeat KC armour in the Sheffield area. However, for unknown reasons the research team undertook no further development and the design remained a concept only. The next patent from Cammell related to projectiles came in 1909 from Edward Kay, a manager at the company. His patent outlined the use of a coil of steel to protect the point of a projectile when perforating armour.[104] While demonstrating some ingenuity, Kay's design had been rendered obsolete by the introduction of the Hollow Cap a year prior. The final designs came in 1914 from Cammell's Sheffield managing director, James McNeill Allan. His 'Allen Cap' design was a solid cap for an AP projectile with a recess ahead of the point of the projectile to provide support during perforation.[105] The design was tested during the Great War, but never entered full scale production. Allen's work had failed to keep up with the work of his contemporaries at Hadfields and Firth, who were advancing designs for oblique attack at the time of his invention. None of the research teams involved with projectiles at Cammell built on what their predecessors had developed, and this discontinuity hampered their technological development. As the cases of Hadfields and Firth have demonstrated, by having a stable research team they could continually produce sub-innovations based on their previous experiences,

[102] British Patent 2,150/1902.
[103] British Patent 12,279/1903; British Patent 12,281/1903.
[104] British Patent 9,215/1909.
[105] British Patent 1,619/1914, p.1.

tacit knowledge, and observed problems during the testing of an innovation.[106] The stability of a research team also allowed for the more rapid realisation and utilisation of knowledge spun-off from armaments research.

The nature of spin-off varied between companies and in part depended on their approach to research and development, and what the key major innovation utilised was. At Firth this was related to the practical use of forging technology and aided the production of commercial products at the Gun Works. The research undertaken at Hadfields, in addition to providing an impetus to refine the construction materials used in the manufacture of their pre-established line of rock and ore crushing machinery, generated information related to the use of nickel-chromium steels, and the effect of various compositions and treatments on the performance of alloy steels. Additionally, building on Hadfield's own knowledge of manganese, further research was conducted regarding controlling the use of this element in nickel-chromium steels and its affect on hardening. These aspects helped to provide a spin-off of metallurgical knowledge at Hadfields, contributing to a pool of information which could be drawn upon by the company's research staff for future armaments and commercial research. Furthermore, part of this pool of information was generated from research dead ends, ideas which failed to go into production or were ultimately not used.

Overall, Hadfield 'never tired of applying his metallurgical brain to the problems involved in the struggle for supremacy between projectiles and armour plate.'[107] By applying metallurgical skill and knowledge Hadfield pioneered the Heclon AP projectile, but importantly his understanding of the commercial potential of the technology enabled him, to generate a spin-off both into and out of armaments production within the boundaries of a single company. Furthermore, Hadfield's process of innovation with AP projectiles, beginning with his father's method of utilising cast steel, demonstrates one version of path-dependent research with projectiles. As Tweedale has rightly stated, as a result of such extensive technological development and testing '…by 1914 Hadfield had made his firm probably *the* world leader in the highly

[106] See Rosenberg, *Black Box*, Chapter 1.
[107] S. A. Main, *The Hadfield's of Sheffield: Pioneers in Steel*, (Unpublished typescript, c.1950), ch.9, p.1., quoted in Tweedale, *Steel City,* p.102.

specialised art of armour-piercing shell manufacture.'[108] Conversely, the research undertaken at Firth into projectiles built on the major innovation of using forged steel, and was based on practical advances rather than metallurgical considerations. The team of Hoyle and Strange clearly demonstrated this, though they were not lacking in inspiration or innovation. This is reflected in their successes, and the credit given to Strange for the invention of the hollow cap. Essentially, Firth provides an intriguing contrast to Hadfields' technological developments with projectiles. Starting with two different major innovations, cast and forged steel, the metallurgist and the practical minded innovators, working in two different research facilities in the same industrial district, demonstrate two *different* approaches to projectile developments, and two examples of technological path dependence. While individually each company was a world leader in projectile technology, their connections and use of patents were central to their ability to innovate, and further profit from investment in research and development.

The Marketing of Projectile Technology: Patents, Licences and Systems

The use of patents was an important part of the armaments industry. They were a means of protecting the expensive research conducted, assisting the sharing of knowledge between companies, and providing an opportunity to generate profits outside of those earned from the companies own commercial application of the technology. In essence, they facilitated the transfer of technological knowledge through licensing agreements both at home and abroad. This use of inter-company and overseas arrangements is counter to what is known about patent licensing. Nelson highlights that 'the limited evidence is that much of patent licensing is between a firm and its affiliates and subsidiaries,' not between potential commercial rivals in the international market as the armaments industry will demonstrate[109] Furthermore, the marketing materials produced by projectile companies emphasised the capabilities of their technology to potential foreign customers. These are important aspects of armaments marketing that have been overlooked by previous studies, which have explored technology to some extent but not the scope of their overseas

[108] Tweedale, *Steel City*, p.103.
[109] R.R. Nelson, 'Capitalism as an Engine of Progress', *Research Policy,* Vol.19, No.1 (1990), p.204.

connections and the patents and knowledge which underpin the products offered.[110] Patents and licensing were also a way of controlling how much technical information left the company, leading to decisions based on what new knowledge would be codified in a patent specification and what remained tacit and owned by the research team of the company. A patent or licence explained how to manufacture a product, not why it was produced in a certain way. This limited the scope a licensee had to modify the design, as details of technical experimentation and failed prior designs are rarely recorded in sufficient detail to facilitate further development from examining patent records alone. For instance, if a licensee adjusted the composition of an alloy steel by even a small margin, or modifying its treatment process, they had no means of knowing if the resultant alterations in the performance of the steel would be advantageous or not. By retaining the knowledge of why a material was produced a certain way research teams could refine a product and develop further sub-innovations based on their prior successes and failures. Overall, this information related to armaments and metallurgy was developed and maintained by independent research teams operating primarily in secret, and provided the core knowledge that facilitated the path-dependent development of armaments technology.

At Firth their means of profiting from patents was with licensing the hollow cap design, granted as part of their agreement with Hadfields in 1910. For royalties on the manufacture of hollow caps included in the arrangement, at the end of each year Hadfields and Firth would compare their production figures and calculated the payments required. From 1911 to 1913, Hadfields produced more hollow caps, leading to £5,970 paid from them to Firth, who never paid Hadfields for using the patents before the Great War. Elsewhere, one of the first licensees of the hollow cap was Krupp of Germany, who began paying royalties from the start of 1912. One third of the royalties from Krupp was paid to Hadfields, Firth retaining the other two thirds. In the first two years of the agreement, Krupp paid Firth £7,328 for the use of the hollow cap, £2,442 of

[110] See R.P.T. Davenport-Hines, 'The British Marketing of Armaments 1885-1935' in R.P.T. Davenport-Hines, *Markets and Bagmen: Studies in the History of Marketing and British Industrial Performance 1830-1939* (Aldershot, Gower Publishing, 1986), and J. Singleton, 'Full Steam Ahead? The British Arms Industry and the Market for Warships, 1850-1914' in J. Brown and M.B. Rose, *Entrepreneurship, Networks and Modern Business* (Manchester, Manchester University Press, 1993).

which was passed to Hadfields.[111] In contrast to British armaments companies, Krupp preferred to export finished weapons rather than techniques in the early 1900s.[112] Firth also licensed the hollow cap to the Bofors Company in Sweden, the Breda Company in Italy, and in the UK to Armstrong, Cammell and Vickers by the end of 1914. With each licence Firth incorporated a clause to facilitate a reciprocal technological exchange, meaning that if any of their licensees developed improvements in the hollow cap design, the details would be given to Firth without cost.[113] While the patents did not detail why hollow caps were made the way they were, practical adjustments could be made by the licensees to the design. However, no evidence of technical information from licensing agreements being returned can be found in the Firth records. The company also received royalties outside of formal agreements with four further Italian shell manufactures, and provided Hungarian company Manfred Weiss with full details of how to produce AP projectiles, along with rights to the Hoyle-Strange patents.[114] These licences allowed Firth to exploit and profit from their technological knowledge in addition to using the Gun Works to manufacture projectiles. By 1914 Firth had become one of the major licensors of projectile caps in the world, principally due to the addition of Strange to the company and his hollow cap design.

Hoyle and Strange were also involved in the development of a range of fuzes for projectiles.[115] These were generally improvements over contemporary designs and allowed Firth to market ‘Projectiles Charged and Ready for Firing’ to foreign customers.[116] A key part of their marketing was to claim that they could offer a projectile immediately ready for service, by combining their ability to produce shells and fuzes with an agreement made with the Cotton Powder

[111] SA, X306/2/3/2/3, Firth Agreements with Harry Bland Strange, 1913-1918. Krupp began licensing the hollow cap from 1 December 1911.
[112] C. Trebilcock, ‘British Armaments and European Industrialization, 1890-1914’, *Economic History Review,* Vol.26, No.2. (1973), p.256.
[113] SA, Hadfields Box 64, Peter Boswell Brown to Robert Hadfield, 18 September 1923; Box 67, Obligations to Licensees and Others on the part of Firths, c.1917; X306/2/3/9/1, Agreement with Bofors Company, 1 February 1913; Wirral Archives (WA), ZCL/5/56, Cammell’s Sheffield Results 1914, p.11.
[114] SA, X308/1/2/1/4/5, Firth’s Report to Brown’s Board, 31 May 1910. Manfred Weiss expanded their munitions output in 1911 and were branded the ‘Hungarian Krupps’ after supplying Russia, Serbia, Bulgaria, Portugal, Spain, and Mexico with projectiles before the Great War. See I.T. Berend, *An Economic History of Nineteenth Century Europe: Diversity and Industrialisation*, (Cambridge, Cambridge University Press, 2013), p.328.
[115] See British patents 23,288/1909, 14,899/1910, 6,923/1911, 22,899/1911, 3,901/1912, 29,145/1912.
[116] SCL, *Thomas Firth and Sons*, *Projectiles Charged and Ready for Firing*, 1912.

Company in 1910 to supply cordite for foreign orders.[117] The Firth 'exploder' fuze was the main design used, and its performance was outlined in marketing materials:

> The delay in this fuze is of such a nature that the shell will be successfully detonated even when broken by impact with the armour (as on active service the majority of projectiles will be), owing to striking the armour at various angles, instead of normally as in the case on the proof ground.[118]

The fuze designs were also licensed to other armaments manufacturers, with Vickers, the Coventry Ordnance Works and the Bethlehem Steel Company in the US all signing agreements before the Great War with the stipulation that all fuzes had to be stamped 'Firths Patent.'[119]

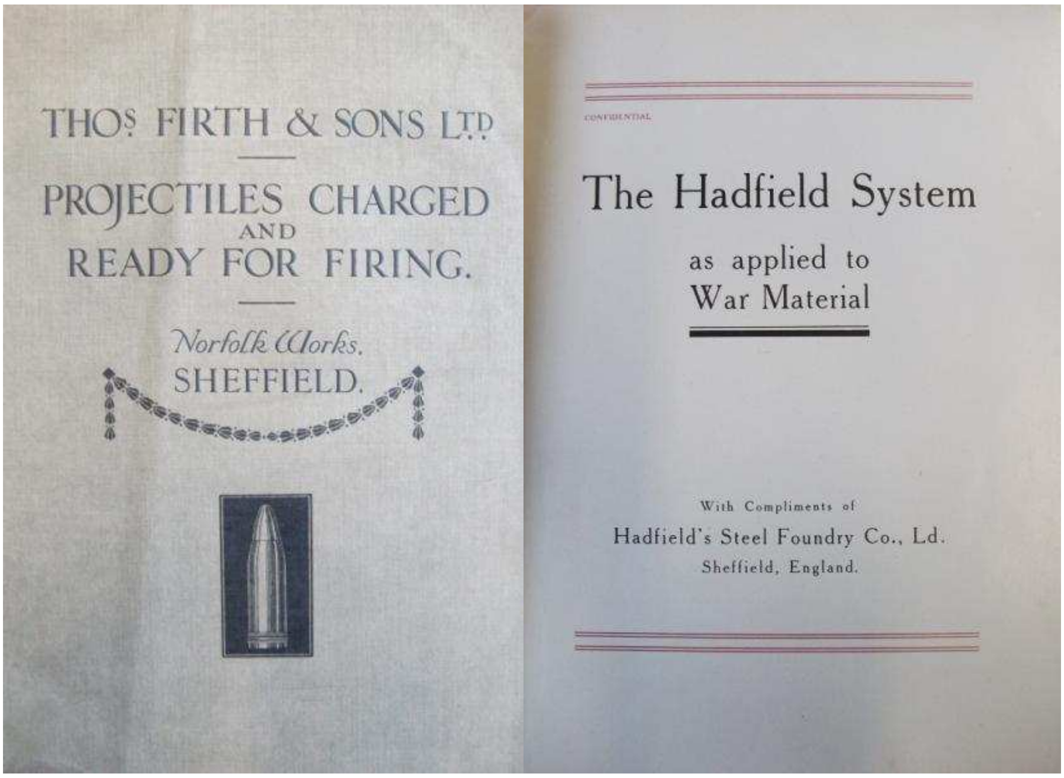

Fig 1.6: Left, Cover of Firth's 'Projectiles Charged and Ready for Firing'. Right, Front page of the 'Hadfield System as applied to War Material'

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117 SA, X308/1/2/1/4/5, Firth's Report to Brown's Board, 25 January 1910.
118 SA, X308/1/2/1/4/5, Firth's Report to Brown's Board, 25 January 1910.
119 SA, X306/2/3/3/2, Agreement with Vickers, 13 September 1913; X306/2/3/9/1, Agreement with Bethlehem Steel, 1 November 1913; X313/1/2/1/8, COW Directors Minutes, 13 November 1913; X306/1/2/3/1/4, Firth's Directors Meeting Minutes, 26 May 1914.

At Hadfields, the use of patents allowed for a combined means of marketing finished products and their method of manufacture to foreign customers. All of the metallurgical and armaments developments produced by Hadfield were placed under patent protection. While covering a range of advances and issues, the patents had two common features. They all were related to producing a superior product, and sought to reduce the cost of producing AP projectiles. These patents would form the basis of the licensing agreements which Hadfields marketed under the banner of the 'Hadfield System as Applied to War Materials.' The relationship between the inventor and the company was an interesting one. In January 1918, Hadfields' acknowledged that the company's business and development was founded upon patent inventions and improvements, and that 219 patents had been taken out by the company in the UK and overseas, 172 by Hadfield and a further 40 jointly by Hadfield and company director Alexander Jack.[120] In addition to the patents which he had personally filed, Hadfield had also gained control of a number of his father's patents upon the foundation of Hadfields as a limited company, and he continued to receive royalties under the company's articles of association.[121] His control over patents was extended in 1897 when the board of directors passed a special resolution granting Hadfield full rights to licence his patents in Europe and the US.[122] As a result, through using the research facilities at *his* company, Hadfield was able to patent *his* inventions, improvements and discoveries, after which he could licence them back to Hadfields and anyone else in order to secure royalty payments. This was in addition to the sizeable dividend payments paid to him as the company's largest shareholder in the years prior to the Great War. Being able to keep Hadfields at the forefront of technological progress in both metallurgical development and armaments technologies was clearly of paramount interest to Hadfield, and his own bank balance.

One example of this agreement in practice comes from the licensing of the Hadfield System to Krupp. Brokered by Hadfield directly with the German company in 1898 for a period of 12 years, and renewed in 1912 for a further six years, the licence covered projectile manufacture and manganese steel

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120 SA, Hadfields Box 59, Patents and Royalties, January 1918, p.2.
121 SA, Hadfields Box 59, Patents and Royalties, January 1918, p.2.
122 SA, Hadfields Box 59, Patents and Royalties, January 1918, p.2.

production, including all associated patents, technological knowledge and information.[123] After signing, the royalties from the arrangement were paid to Hadfield, not the company. A minimum payment for the first 12 years was set at £925 per year, rising to £1,500 per year in 1912, without the payment of any additional royalties which included £5 per ton of AP projectiles sold. Additionally, if any products made under the agreement were exported, Krupp would pay double the royalties on the product.[124] The agreement with Krupp returned Hadfield a minimum of £15,000 from its signing in 1898 to the end of 1914, without a single product being sold by the German manufacturer. Krupp also agreed to consider the use of all future inventions Hadfield would patent in Germany, which thereafter would be jointly patented by the two.[125] Essentially, this gave Krupp access to the AP projectile technology designed to defeat their KC armour, in widespread use by all British armour manufacturers and several others around the world at the time.

The Hadfield System as Applied to War Materials offered potential customers a service, not simply a technological product, and was used as a marketing tool to gain new orders for the Heclon and Eron. It also emphasised Hadfields' ability to produce common lyddite, shrapnel and practice shells, and the ERA steel products Hadfields could produce at their plant.[126] The Hadfield System also offered licensing agreements for all of their products and patents, giving other companies and nations the opportunity to produce Heclon and Eron projectiles themselves, in return for royalty payments. This licensing system had multiple benefits for Hadfields. While marketing the means of producing advanced weapons to potential customers, the Hadfield System was not an arrangement which revealed the decades of research into armaments development at Hadfields, nor the full details of how a projectile and its cap worked in practice. While the methods of production were licensed, the knowledge remained private. As discussed above, the details in a patent specification only revealed what to include in an alloy steel composition, not the reasons why such elements were required. By licensing their production methods, Hadfields were able to further profit from their research, and with the

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[123] SA, Hadfields Box 59, Hadfield-Krupp Agreements, 1898 and 1912.
[124] SA, Hadfields Box 59, Hadfield-Krupp Agreements, 1898 and 1912, p.13.
[125] SA, Hadfields Box 59, Hadfield-Krupp Agreements, 1898 and 1912, p.4.
[126] SCL, *The Hadfield System as Applied to War Materials*, n.d., probably 1911, p.7-15. The development of ERA steel is explored in the following chapter.

perpetual cycle of new developments in the armaments industry, licensing agreements had the potential to be rapidly rendered obsolete, at which time Hadfields could licence a new development in the field. In essence, by utilising licensing agreements Hadfields could control the flow of their technological research and production methods leaving the company, while also making a return on their research investment in projectile technologies.

As a result of the Hadfield System, Heclon projectiles were produced under licence in America prior to the Great War as part of an agreement with the US Army. Signed in 1914 for 12 years, the agreement encompassed 17 patents for projectiles and ERA steel registered in the US between 1899 and 1911.[127] The agreement demonstrates the progressive growth of the Hadfield System over time, and highlights the constant development of sub-innovations patented to refine the performance of their armaments products. As part of an agreement with the Japanese Government to supply the Imperial Japanese Navy in 1910, Hadfields also provided training to a small number of Japanese students at the Hecla Works.[128] Overall, Hadfield's extensive patent and licensing arrangements served a multitude of purposes. The Hadfield System provided commercial opportunities to exploit their patents and make a return on research while protecting the knowledge and experience behind them. On the other hand, the arrangements made with Cleland Davis and Firth served to both protect and extend Hadfields' patents and knowledge in projectile cap technology and manufacture in order to remain at the forefront of developments. Essentially, the control and development of armaments knowledge and technology were central to the strategy of the company.[129]

By examining all of the technological connections related to projectiles made by Firth and Hadfields at the outbreak of the Great War (Figure 1.7), it is possible to demonstrate the extent to which licences and agreements were a core feature of the industry. While reciprocal licences were commonly utilised to ensure the sharing of technological advances, the connection between Hadfields and Firth from 1910 is the most important. This agreement formalised the relationship between the two and covered any future technological

[127] SA, Hadfields Box 59, Hadfields Patents and Royalties, January 1918, p.37.
[128] SA, Hadfields Box 66, Hadfields-IJN Agreement, 1911.
[129] Lipartito has highlighted how technological development is central to business strategy. See K. Lipartito, 'Innovation, the Firm, and Society', *Business and Economic History*, Vol.22, No.1 (1993), p.93.

developments in addition to the hollow cap. These connections, and those with key inventors in Robert Abbott Hadfield and Harry Bland Strange, were an important element of projectile developments in Sheffield. Nelson and Rosenberg outline how the connections between people and institutions are a key part of technological developments.[130] The relationships outlined can be viewed as part of an armaments-metallurgy-steel innovation system which developed prior to the Great War with Sheffield at its centre. This system emerged from the fusion of metallurgical knowledge and armaments production and, in this instance, facilitated the development of projectiles and a pool of metallurgical information which could be built upon for both commercial and armaments developments. These connections highlighted are solely for projectiles, and will be developed in the following chapter's discussion of other aspects of armaments technology

Conclusion

From exploring the evolution of AP projectiles in Sheffield, a number of core aspects of armaments development have been highlighted. Hadfields and Firth both innovated in different ways, related to the productive specialty of each company and the research background of the research team involved. Hadfields built on the major innovation of using cast steel for projectiles, and utilised the metallurgical knowledge of Robert Abbott Hadfield to develop a number of sub-innovations which demonstrate the path dependent nature of projectile research at the company. Conversely, Firth's major innovation was in the use of forged steel for projectiles, using practical knowledge of both steel manufacture and military use of shells from their research team of James Rossiter Hoyle and Harry Bland Strange. The sub-innovations developed at Firth also highlight another example of path-dependent technological development of projectiles, different to the research undertaken at Hadfields. One of the key factors in facilitating this type of innovation was a consistent research team, the example of Cammell with their inconsistent research teams demonstrating the issues of a changeable leadership for armaments research and development. Projectile developments also demonstrate the spin-off of

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130 R.R. Nelson and N. Rosenberg, 'Technical Innovation and National Systems' in R.R. Nelson, *National Innovation Systems: A Comparative Analysis* (Oxford, Oxford University Press, 1993), p.4.

metallurgical knowledge from armaments research, contributing to a pool of information available for future use. This was part of a complex and long-established continuum between armaments and commercial metallurgical developments in Sheffield. The value of patents for armaments companies has also been demonstrated, facilitating inter-company collaboration and knowledge exchange, and providing a means of marketing technology and further profiting from investment in research and development. The connections developed between Sheffield companies can be seen as an essential element of an innovation system centred on the city. However, projectiles are only one aspect of armaments technological development in Sheffield. Armour was equally important for the advancement of metallurgical knowledge, as the following chapter will explore.

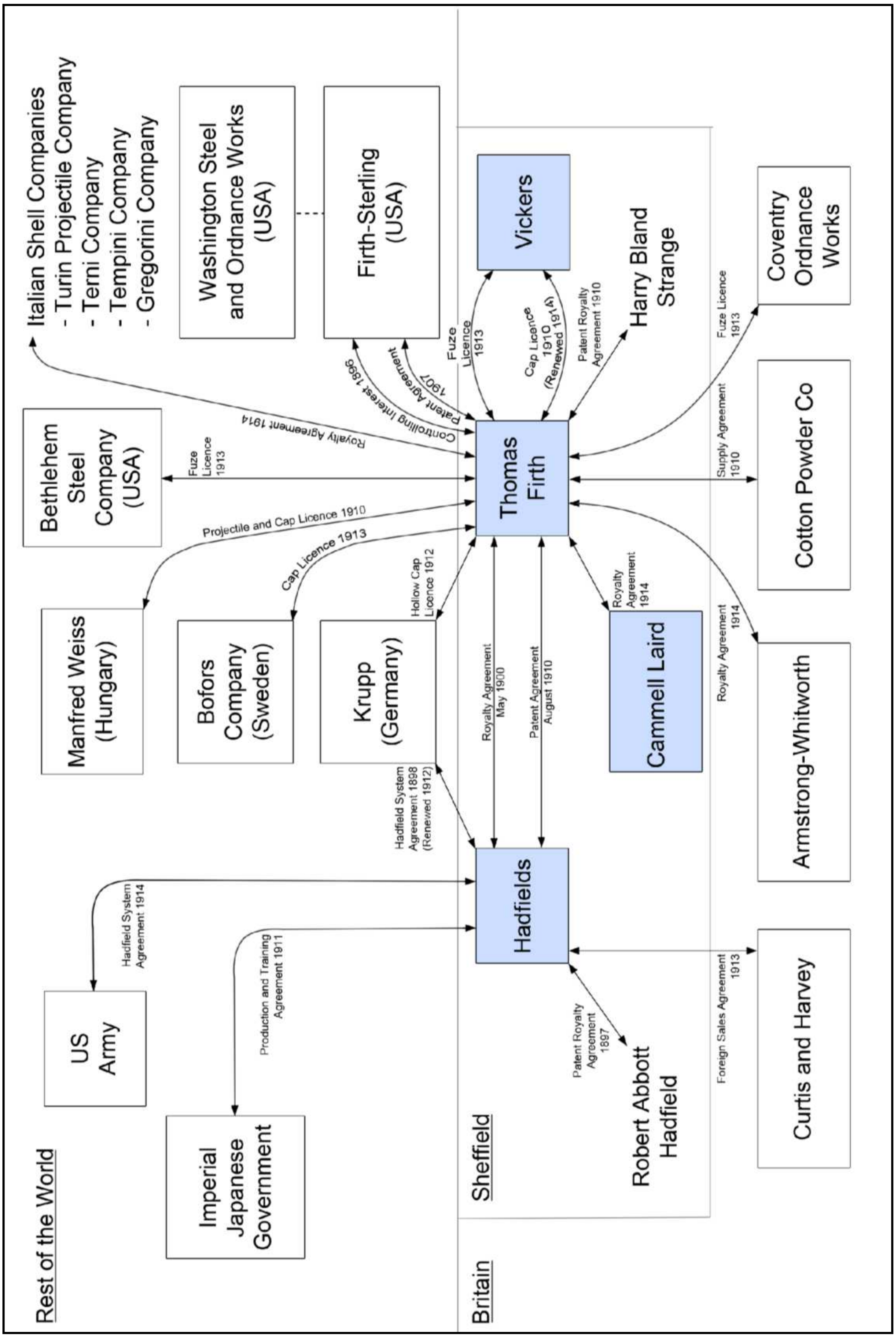

Figure 1.7: Technological arrangements for projectiles, 1914.

Chapter 2: Armaments Technology 1900-1914 – Armour, Metallurgy and Innovation Systems

Projectiles were not the only area of armaments experimentation which took place in Sheffield, and this chapter will investigate three further elements of armaments research and development in the area. Firstly, there will be an exploration of armour research and production methods by Brown and Cammell, considering the technological environment in which they operated and the metallurgical knowledge their experimentation created. Secondly, the use of metallurgical knowledge to support new areas of armaments research will be investigated, examining Hadfields' ERA steel and Harry Brearley's work in developing stainless steel. Finally the chapter will advance a model of how innovation occurred in the Sheffield armaments industry, and evaluates the technological connections between armaments companies and the wider Sheffield steel industry as part of an innovation system centred on the city.

Sheffield and the Technology of Armour

As highlighted in the previous chapter, the major innovations which initiated the development of armour piercing (AP) projectiles in Sheffield were casting and forging technology, both central to the manufacture of steel. While armour production also drew on these important techniques, the major innovation central to armour production was the introduction of bulk steel manufacturing techniques from the 1860s, first the Bessemer process and in the 1870s the Siemens-Martin open-hearth furnace. The introduction of these process innovations facilitated a move to producing steel by the ton rather than by the pound with older methods like the crucible. Brown and Cammell were the first two companies to introduce the Bessemer converter and quickly used the process to capture the market for steel rails.[1] As the demand for railway materials declined in the early 1870s, to utilise their steel making capacity the companies turned to armour plate and armaments, which were 'high-value products and in that respect they reaffirmed Sheffield's quality emphasis.'[2] This was not a new product for either company; Brown pioneering the use of iron

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[1] On the Sheffield rail trade, see K. Warren 'The Sheffield Rail Trade, 1861-1930', *Transactions and Papers (Institute of Geographers)*, Vol.34 (1964), pp.131-157.

[2] K. Warren, *The Geography of British Heavy Industry Since 1800* (Oxford, Oxford University Press, 1976), p.44.

armour for ships in 1859, and Cammell commencing manufacture soon after. By 1867 three quarters of the British Navy's ironclads were protected with Brown's armour. By that date 'Browns were said to be rolling some of the largest armour plates in the world – 21 tons – by a process that was clearly pushing the limits of available technology.'[3] The company had captured first mover advantages with their armour production and were part of a duopoly with Cammell of armour supply to the Admiralty. Nevertheless, commencing armour production meant committing to a potentially unending path of technological development in order to maintain a position in the industry. Warren has summarised the market-cum-technological environment in which armour producers operated:

> If any producer failed to respond to the demands of naval architects it would loose business and be left with underused plant representing immense capital outlay. In short there had to be a ceaseless pursuit of an 'improved' product and therefore modifications of processes that required large-scale, apparently unending, capital investment. These conditions forced producers to make every effort to get sufficient orders to keep their plants in condition to meet ever more exacting specifications.[4]

Commencing armour production was a long-term strategy for both companies. Once initiated, they continuously sought to keep their plant up to date and maintain their position as the leading armour manufacturers in Britain. The introduction of bulk steel to the manufacturing process also saw each company innovate in different ways, Brown led by the Ellis family, and Cammell by the Wilson family.

At Brown, whose company history is indelibly linked to the history and technological development of armour plate in Britain, in 1871 company chairman John Devonshire Ellis patented a means of cementing an iron armour plate. The cementation process increased the carbon content of the face of the armour to improve its resistance. After test plates proved unsatisfactory, the method did not go into production.[5] As we shall see, armour innovations were difficult to develop and introduce, this case demonstrating one of the first

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[3] G. Tweedale, *Steel City: Entrepreneurship, Strategy and Technology in Sheffield 1743-1993* (Oxford, Clarendon Press, 1995), p.73.
[4] K. Warren, *Steel, Ships and Men: Cammell Laird and Company 1824-1993* (Liverpool, Liverpool University Press 1998), p.80.
[5] Sheffield City Library (SCL), *John Brown And Company Limited*, 1903, p.5.

examples of this in the industry. Research dead-ends were a common feature of developments with armour, but this did not deter inventors' efforts. Ellis later had success with a method of producing compound armour consisting of an iron armour plate with an outer steel skin. Patented in 1877 and used widely for the next 15 years, the process included a perfect weld between the iron plate and the hardened steel skin.[6]

At Cammell, central to their armour developments from the 1870s was Alexander Wilson, an engineer who joined the company after leaving University in the 1850s. Wilson worked as assistant managing director from 1864 under his brother George and in 1900 it was said of Wilson that 'with the development of the armour plate industry his name is indissolubly associated.'[7] In 1876, Wilson developed and patented a method of producing compound armour of steel backed with iron, a year ahead of Ellis at Brown. The Wilson method was an important competitive alternative. The process involved heating a wrought iron plate to the required temperature and placing it 'in an iron mould on trannions.' Thereafter, 'the mould was turned upright and Bessemer steel was poured in front. After solidifying, the plate was then rolled to thickness, bent, planed and fitted.'[8] The proportions of the plate were one third steel, the remaining two thirds iron. Cammell were able to produce plates up to 19 inch in thickness with the method, and licensed the process to three French armour manufacturers.[9] Wilson, in his role as managing director from 1885, remained active in developing armaments technologies into the 1890s. One invention was a method for carburising armour, using electricity to heat two plates connected via a diode with a layer of carbide between them to increase the carbon content of the face of the armour, and offered an alternative to gas or coal heated carburisation furnaces.[10] Wilson was a prodigious innovator, and presided over the introduction of the next two changes in armour production at their Cyclops

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[6] SCL, *John Brown And Company Limited*, 1903, p.5. See also 'Armour for Ships (1860 to 1910)' in *Iron and Coal Trades Review*, 21 July 1911, p.91. This article reprinted a speech at the Institute of Naval Architects Jubilee Meeting by Charles E. Ellis, son of John Devonshire Ellis.

[7] SCL, *Charles Cammell & Co Cyclops Steel and Iron Works*, 1900, p.2. For an overview of Alexander Wilson's career see *The Engineer*, 3 May 1907, p.454.

[8] A.D. Stacey, *An Historical Survey of the Manufacture of Naval Armour by Vickers Sons & Co., and their Successors* (Sheffield, Unpublished Typescript, 1956), p.16. A trannion is a device which allowed the iron armour to be moved from horizontal to vertical.

[9] Stacey, *Armour*, p.15.

[10] British Patent 12,782/1896.

and Grimesthorpe works, the Harvey and Krupp Cemented (KC) methods.[11] The introduction of these methods at Brown and Cammell marked two key changes in how armour was produced in the industry. Firstly, it introduced the standardisation of armour production techniques by the Admiralty, and thereafter each armour manufacturer in the country had to utilise the same method to ensure consistent performance with each ship constructed. In Sheffield this now included Vickers, who had commenced armour production in 1888 to compete with Brown and Cammell.[12] Essentially, the Admiralty had seized control over the universal adoption of new methods of armour production. Consequently it meant that Brown and Cammell, consistent innovators since commencing armour manufacture, would be increasingly reliant on outside licences and designs for the first time. However, Brown were able to avoid paying royalties for the Harvey method due to a coincidence over patent filings in Britain and America.

At the heart of Brown's research and development of armour plates from the 1890s was Captain Tolmie John Tresidder, a 'retired Royal Engineer, a great mathematician and an authority on ballistics.'[13] Tresidder had trained at the Royal Military Academy before joining the Royal Engineers, where he became a Lieutenant in 1870 and a Captain in 1882. He retired from the Army in 1887 and joined Brown as manager of the armour department the same year, before gaining a directorship in 1894. It was said that his 'mathematical attainments and aptitude for ballistics found use with his work with John Brown where he devoted himself chiefly to the development of armour and armour piercing projectiles.'[14] Brown had been able to hire an ex-military expert whose knowledge and expertise helped to maintain the company at the forefront of armour developments. Tresidder invented in 1891 a means of chilling armour during its production with a high pressure water spray in order to harden the outer face of all-steel plates. This treatment had been developed contemporaneously with the American engineer Hayward Augustus Harvey, whose name was given this method of production. Tresidder patented the

[11] On the process of armour manufacture at Cammell, see SCL, *Charles Cammell & Co Cyclops Steel and Iron Works*, 1900.
[12] J.D. Scott, *Vickers: A History* (London, Weidenfeld and Nicolson, 1962), p.40.
[13] A. Grant, *Steel and Ships, The History Of John Browns* (London, Michael Joseph, 1950), p.35. See also 'Modern Armour and its Attack' by Tresidder in *Transactions of the Royal Institute of Naval Architects* (1908).
[14] The information on Tresidder's military career is from his obituary in *The Engineer,* 27 March 1931, p.351.

method in Britain one day ahead of Harvey in the US, resulting in the patents being interchangeable and licensed together to armour manufacturers. This resulted in Brown paying no royalties, having a legitimate claim to have invented the method.[15] Despite providing improved resistance to attack by projectiles over compound armour, the main technical flaw with Harvey armour was its liability to crack after being hit due to the structure of the steel after treatment.[16] This issue was solved with the introduction of Krupp Cemented (KC) armour by Krupp just three years later.

Krupp's KC armour was first produced in 1894 and established the use of nickel-chromium steel for armour production, containing 4% nickel and 2% chromium.[17] The treatment of KC armour was similar to the Harvey method, using carburisation and water cooling, with a new heat treatment applied to alter the structure of the steel for the new method of manufacture. This use of similar techniques meant that the KC and Harvey patents were packaged together for licensing purposes. The updated treatment prevented the plate from cracking after a projectile attack as it dissipated the blow more effectively.[18] The process of production was complex, time consuming, yet at the vanguard of metallurgical developments:

> To make a single plate of armour, by the methods of 1896, required doing extraordinary violence to metal. To begin with, an ingot of nickel steel, weighing 52 tons and about one yard in thickness was compressed in a rolling mill, at a single heat, within thirty minutes, to a new thickness of just six inches. This so altered the molecular structure as to enormously increase hardness. Then charcoal was forced into the surface of the metal, under heavy heating, for 10-12 days. This introduced a larger carbon molecule into the already modified molecular structure of the steel. The plate was then bent to the desired shape in an 8,000-ton hydraulic press; then planed, edged and faced to its finished contours. It was these operations which required machine tools and cutting materials of a size, speed and force rarely needed in civilian

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15 SCL, *John Brown And Company Limited*, 1903, p.6., Grant, *Steel and Ships*, p.35, Scott, *Vickers, pp.*42-3.
16 'Armour for Ships (1860 to 1910)' in *Iron and Coal Trades Review*, 21 July 1911, p.91.
17 For a description of the development of armour at Krupp, see Stacey, *Armour,* Chapter 2: The Development of the Krupp Process. An outline of the process and its introduction in Sheffield is also discussed in Grant, *Steel and Ships*, p.36.
18 'Armour for Ships (1860 to 1910)' in *Iron and Coal Trades Review*, 21 July 1911, p.91.

> industry. Once treated to their ministrations, the plate was further hardened by plunging into cotton-seed oil. Then it was alternately heated and water cooled to harden the carbonized belt on the face of the plate, by now some three inches deep. By this stage, the armour was too hard to cut at all, and any final adjustments had to be made with massive grinding machines. *The result was the most advanced metallurgical product of its day.*[19]

The Sheffield armour manufacturers had no issues obtaining licences or technical advice from Krupp to produce KC armour.[20] A clause in the Krupp licence required any licensees to communicate any improvements they made in the manufacture of the armour back to the inventor.[21] Any competitive advantages from the advance of armour would be short-lived in this international free exchange of knowledge, with each producer thereafter able to produce an advanced product. Krupp had chosen to be open with the licensing of the method due to profit considerations, due to the potentially limited markets for the German manufacturer. The British Admiralty would never order from a German company, yet they were open to the British armour manufacturers using a German design and paying royalties back to Krupp. This increased the return the German company made on their technological investment, much like their counterparts with projectiles explored in the previous chapter. By 1898 it was reported that 'our three great Sheffield armour-plate factories have achieved success in the manufacture of Krupp process plates nearly 12 inch thick.'[22] Despite the rapid adoption of the approach by Sheffield companies, its introduction had caused some severe issues at the armour plants. The Admiralty initially deliberated over the best type of armour which led to the stoppage of orders, and at Brown the management had trouble keeping the

[19] C. Trebilcock, 'Science, Technology and the Armaments Industry in the UK and Europe, with special reference to the Period 1880-1914', *The Journal of European Economic History*, Vol.22, No.3 (1993), pp.572-573. Emphasis added. This quote also demonstrates the influence of spin-off from armaments to the promotion of the high speed steel and machine tool industries. For more information see C. Trebilcock, '"Spin-Off" in British Economic History: Armaments and Industry, 1760-1914' *Economic History Review*, Vol.22, No.3 (1969), pp.474-490.
[20] Tweedale, *Steel City,* p.102, Grant, *Steel and Ships*, p.36.
[21] *Vickers News*, 15 November 1919, pp.80-83; Scott, *Vickers,* pp.47-8. Vickers introduced a non-carburised version of Krupp armour, with the information about its manufacture freely shared with Krupp.
[22] *The Engineer,* 21 October 1898, p.402.

works in operation.[23] Once KC armour was universally adopted, it required significant new capital investment for each armour plant. Grant concludes, the introduction of KC armour by Brown 'had forced the company to reorganise the armour plant, spending a good deal more capital.'[24] In 1895 Brown commenced expanding the armour plant by adding Krupp furnaces (for carburisation), Harvey furnaces (for chilling armour), a new armour rolling mill, 10,000 ton armour forging press and an 8,000 ton armour bending press, with the extensions completed by mid-1901.[25] In 1903 the capacity of Brown's armour plant had increased to 10,000 tons a year.[26] Cammell's first KC plate was produced in 1896, preceded by a large capital outlay and the removal of the Bessemer plant at the Cyclops Works to clear the space required.[27] By 1900 Cammell had produced armour for over 200 ships, and claimed to be one of the largest armour producers in the world.[28] Overall, their new plant required for maintaining armour production was advanced and expensive, and had limited use for commercial work.

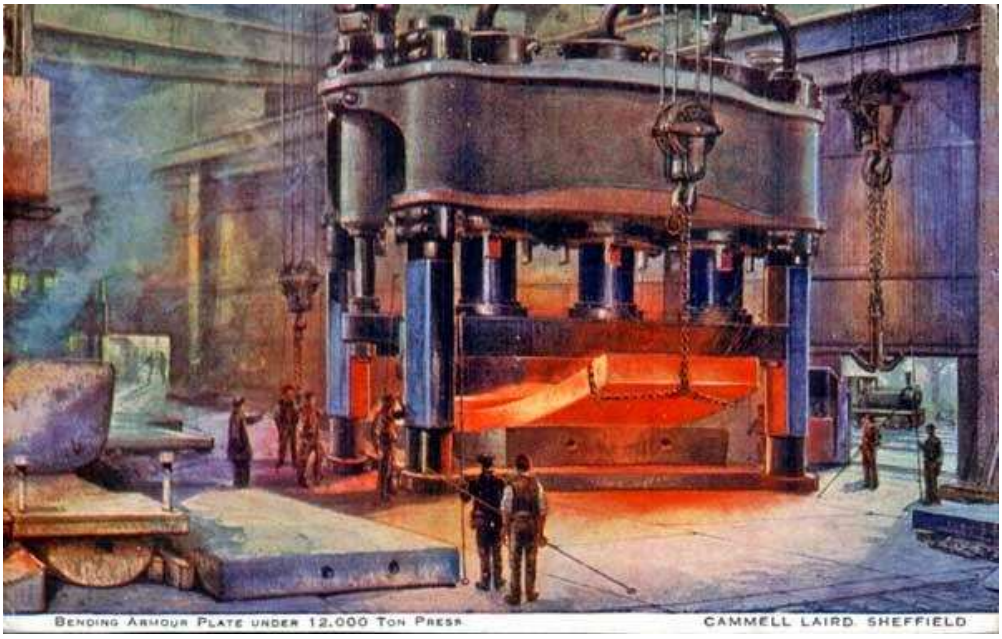

Figure 2.1: 12,000 ton armour bending press at Cammell

[23] SA, X308/3/1/3, Brown's Balance Sheet and Annual Report 1901-1902, p.9. There had been similar stoppages in 1877, when discussions began regarding discontinuing the use of armour plates, and in 1888, when discussions about iron, steel or compound armour were underway. At Brown the 1888 stoppage led to slackness in the armour plant for four months.

[24] Grant, *Steel and Ships*, p.36.

[25] SCL, *Firth-Brown: 100 Years in Steel*, 1937, p.14; SA, X308/3/1/2, Brown's Balance Sheet 1901.

[26] SCL, *John Brown And Company Limited*, 1903, p.7.

[27] Warren, *Steel Ships and Men*, p.84. The testing of a Cammell KC plate is described in *The Engineer*, 11 November 1898, pp.470-1.

[28] SCL, *Charles Cammell & Co Cyclops Steel and Iron Works*, 1900, p.7, Warren, *Steel, Ships and Men*, p.85.

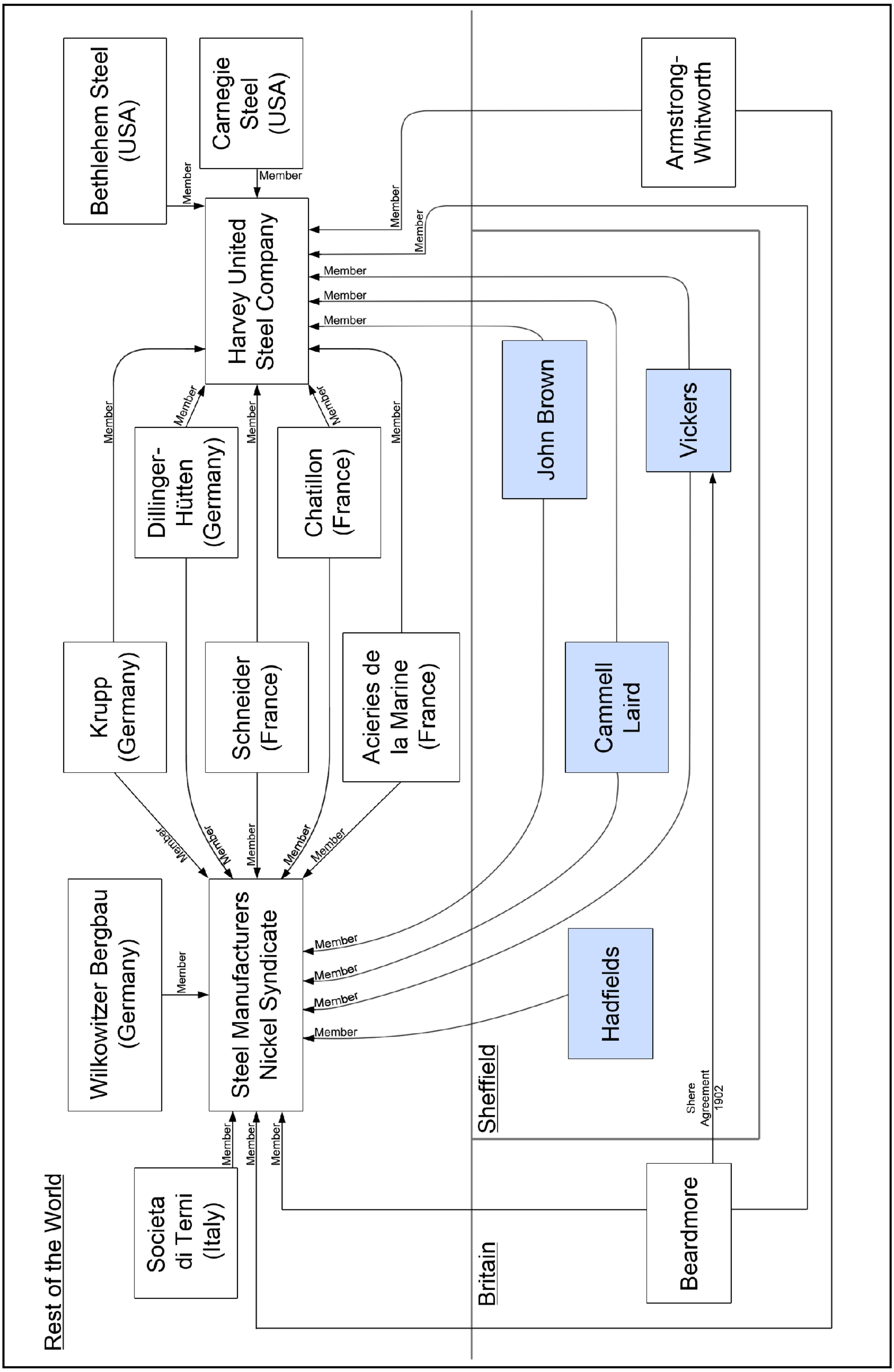

Figure 2.2: Armour relationships in 1908 before dissolution of the Harvey United Steel Company

The introduction of KC armour also required the coordination of patents, licences and royalty payments. Despite the armour's German origin, it introduction was not part of an international conspiracy, but simply a reflection of the British Admiralty's preference for Krupp armour after extensive deliberations regarding the best armour for the Royal Navy.[29] Nevertheless, for the duration of the patents the British armour manufacturers were required to provide Krupp with a royalty of £4 or £5 per ton produced.[30] From 1900 both the Harvey and Krupp patents and licensing rights belonged to the British-based Harvey United Steel Company, with shareholding members in four countries and Albert Vickers as its chairman.[31] The members of the group from Britain were Brown, Cammell, Vickers, Armstrong, and from 1902 Beardmore; from Germany, Dillinger Hütten, and Krupp; from France, Acieries de la Marine, Schneider, and Chatillon; and from America, Bethlehem and Carnegie. In addition to dealing with royalties, the group also divided orders for armour from countries outside of their members between them. The American companies voluntarily left in 1908, seeing the group as no longer to their advantage, and once the Harvey and Krupp patents expired in 1905 and 1909 respectfully, the group voluntarily wound up, finally coming to a close in 1912.[32] Thereafter, the former members were able to continue producing KC armour free of royalties. The production of KC armour also required its manufacturers to secure supplies of nickel, and in 1901 the Steel Manufacturers Nickel Syndicate was established by Vickers, Armstrong, Brown, Cammell and Beardmore to use their combined purchasing power to arrange a preferential supply agreement with La Société de Nickel, at the time the world's leading producer of Nickel.[33] By 1908 its membership had grown to include all the European members of the Harvey United Steel Company, Hadfields in Britain, Wilkowitzer-Bergbau in German, and Societa di Terni in Italy.[34] The relationships between the armour producers and these international groupings before the dissolution of the Harvey United

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[29] B. Collier, *Arms and the Men: The Arms Trade and Governments* (London, Hamish Hamilton, 1980), p.60.
[30] Scott, *Vickers*, p.59.
[31] Scott, *Vickers,* pp.86-7; M. J. Bastable, *Arms and the State: Sir William Armstrong and the Remaking of British Naval Power, 1854-1914* (Aldershot, Ashgate, 2004), p.214.
[32] *Iron and Coal Trades Review,* 3 April 1914, p.525. On the Harvey United Steel Group, and its predecessors, see Scott, *Vickers*, pp.86-87.
[33] G. Boyce, 'The Steel Manufacturers' Nickel Syndicate Ltd., 1901-39: Assessing the Conduct and Performance of a Cooperative Purchasing Organisation', *Australian Economic History Review*, Vol.38, No.2 (1998), p.156.
[34] Boyce, Nickel, p.158.

Steel Company in 1908 are shown in Figure 2.2. The use of syndicates was seen as an efficient means of sharing knowledge related to KC armour, and assisting in reducing the cost its production. In particular, the positive experience of Brown within the syndicate led its management to consider the adoption of the model for a new armour design in 1911.

Brown had provided access to their Krupp and Harvey furnaces for experiments with a new method of armour production to General Feodosieff, an inventor and armaments expert.[35] The proposed treatment was provisionally protected by patents, and created a plate of 'especial quality.'[36] Before applying for a patent, undertaking any testing or the design being accepted by the Admiralty, Brown's Works Committee 'suggested that, if patented, Messrs Krupps' Patent might be taken as example' to utilise the design with international manufacturers through the establishment of a new syndicate.[37] The suggestion of a licensing syndicate so early in the process development also highlights the insatiable desire to control the commercial utilisation of armaments technology by Brown's management. Company managing direction William Ellis began to formulate an agreement with Feodosieff for his designs in late 1911, but encountered issues with the Government and their reluctance to accept armour made by the process. A test plate was suggested to be submitted to prove its resistance, though no further record of the process can be found in Brown's records and the process never entered production.[38] Dead ends were a common feature of armour research and development, as experimentation utilising metallurgical knowledge and refining new alloy steels for armour from 1900 time and again demonstrated.

One of the key contributions of KC armour to the Sheffield armaments industry was in its pioneering use of nickel and chromium for the production of armour, in conjunction with an innovative treatment. Essentially, after the introduction of KC armour and the development of new AP projectiles metallurgical knowledge was used to defeat metallurgical knowledge in a perpetual technological war waged between members of the Sheffield armaments industry, using research facilities in walking distance from each

[35] No information regarding the business or military background of Feodosieff has been found.
[36] SA, X308/1/4/1/1/1, Brown's Works Committee Minutes, 30 October 1911. Spelling varies for the General's name between Feodosieff and Feodiesief in the Minutes. No information on the process of production or its patents has been found.
[37] SA, X308/1/4/1/1/1, Brown's Works Committee Minutes, 30 October 1911.
[38] SA, X308/1/4/1/1/1, Brown's Works Committee Minutes, 27 November 1911, 10 June 1912.

other. Each side also consistently believed they would again either keep or retain the upper hand, Charles Ellis remarking in 1908 that:

> 'the old fight which has been going on between projectiles and armour, I think now for forty-four years, still goes merrily on. It may be that the capped projectile is, at the present moment, the winner, but I daresay that is a position of honour which it will not hold, at any rate unchallenged, very much longer.'[39]

Brown and Cammell, like their counterparts in Firth and Hadfields discussed in the previous chapter, were involved with commercial metallurgical research alongside their armaments developments. Cammell were committed to alloy steel research from the 1890s, when the company appointed Thomas Middleton as head metallurgist. Middleton suggested that the company install a metallographic laboratory to examine the structure of steel in 1902, and the following year he is believed to have produced a stainless steel knife, though the air of secrecy around Cammell's research laboratories and his own reserved character prevented the further publicity of his achievements.[40] Nevertheless, the company possessed modern research facilities for metallurgical developments and by 1919 they had also recruited 9 graduates in engineering and metallurgy from the University of Sheffield.[41] Brown also had a long history of metallurgical developments, in 1871 chromium steel had been made for the first time in England at the Atlas Works, and experiments with tungsten for tool steels had also been undertaken before 1900.[42] In 1903 the works were described as possessing an extensive chemical laboratory with a staff of fourteen chemists, and by 1919 Brown had employed eight of Sheffield University's graduates in engineering and metallurgy.[43] One of their main roles was the testing of armour. Every plate was subjected to three or four chemical analyses and five or six mechanical tests. Armaments manufacture clearly encouraged the development of metallurgical analysis.[44] Ensuring accuracy in the composition of the steel, and the uniform treatment of armour were essential to guarantee a consistent performance. Armour production and development

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[39] *Transactions of the Royal Institute of Naval Architects* (1908), p.47.
[40] Tweedale, *Steel City,* p.109, p.121.
[41] M. Eason, *Business, Training and Education: Sheffield circa 1880-1940,* Unpublished PhD Thesis, Sheffield Hallam University (1997), Appendix D.
[42] SCL, *Firth-Brown: 100 Years in Steel*, 1937, p.59.
[43] Eason, Appendix D.
[44] SCL, *John Brown And Company Limited*, 1903, p.10; Tweedale, *Steel City*, p.110.

also demonstrate that the 'rule of thumb' methods of Sheffield's steel industry were declining with the development of more precise approaches to steel making though these older technologies to production and research did not disappear overnight.[45] Nevertheless, the use of alloy steels for armour made accuracy a paramount consideration at both companies.

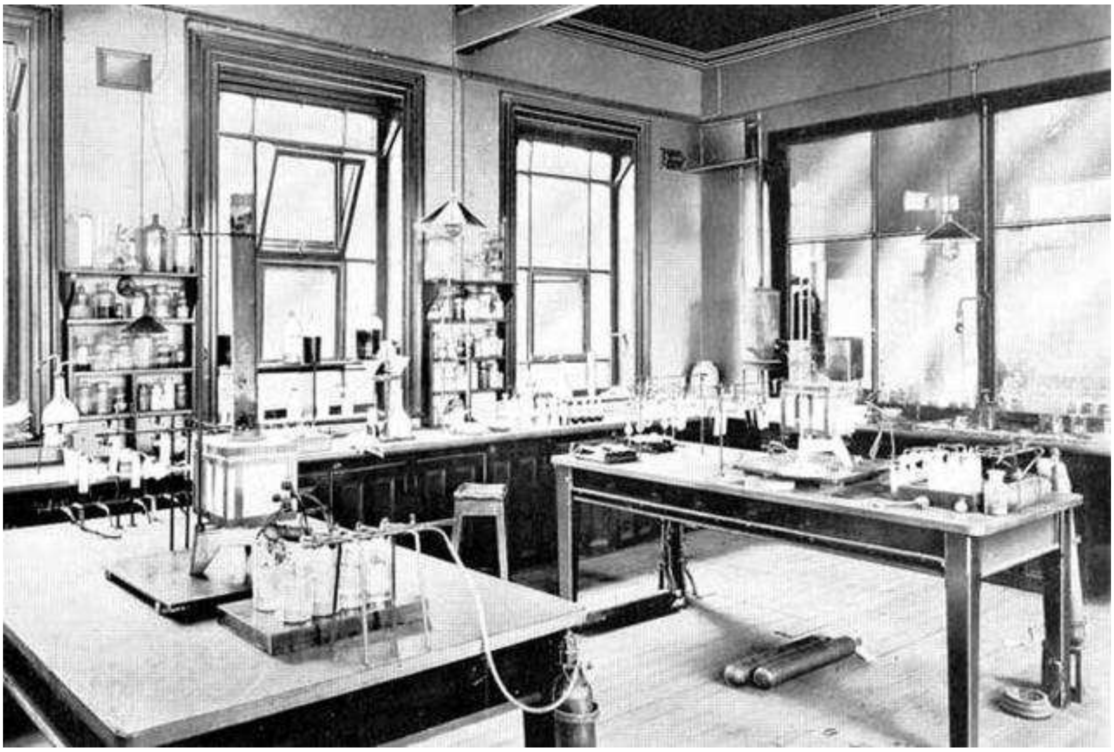

Figure 2.3: The Research Laboratory at Cammell-Laird

Research into new alloy steel compositions for armour continued at Brown and Cammell after the introduction of KC armour, and the installation of new Harvey and Krupp treatment furnaces in the 1890s. Three examples demonstrate this continued research at the two companies; the research teams involved combining metallurgical and armaments knowledge for the advancement of the product. While ultimately research dead-ends, each demonstrates an important spin-off of new metallurgical knowledge.[46] At Brown, Tresidder had begun experimenting with the use of tungsten in armour from the 1890s, an element used in small quantities for tool steels at the company. While not directly commenting on Brown, Trebilcock has highlighted that 'one

[45] G. Tweedale, 'The Business and Technology of Sheffield Steelmaking' in C. Binfield, R. Childs, R. Harper, D. Hay, D. Martin and G. Tweedale, *The History of the City of Sheffield 1843-1993 Volume 2: Society* (Sheffield, Sheffield Academic Press, 1993), p.156.

[46] See Trebilcock, Spin-Off, for a discussion of spin-off in the British Armaments industry.

Sheffield armourer was so far ahead of his time – by decades – that he was experimenting as early as 1895 with a tungsten alloy for naval protection.'[47] The emphasis is clear; using tungsten for alloy steels was developing knowledge at the forefront of metallurgical progress in the Sheffield area, and the fusion of armaments and metallurgical research had benefits for both fields. Tresidder continued developing the armour and in 1903 patented a version of tungsten armour which incorporated 0.3% carbon, 0.3% manganese, 0.3% tungsten, and 2.5% of nickel, treated using the same production facilities at the Atlas Works for KC armour.[48] Furthermore, Tresidder suggested the material could be used in the manufacture of safes.[49] The potential commercial spin-offs from research were clearly considered by armaments experts during their experiments, in addition to developing their understanding of metallurgy.

At Cammell, their managing director Frederick Charles Fairholme developed a new armour steel and treatment in 1903 which they suggested could also be used for projectiles.[50] The most innovative aspects of the design were in the alloy steel composition, and the method of cementation. The armour contained 1% molybdenum or tungsten, 3½% chromium and 0.6% carbon, eliminating the use of nickel with the material. The cementation process moved beyond using solely carbon, typically in the form of charcoal, to increase the hardness of the exterior face of the plates as had been the case in the production of KC armour. For this method, the face to be hardened was heated in contact with boron, tungsten, molybdenum or vanadium. The use of these elements increased the resistance of the armour.[51] This was certainly developing knowledge at the forefront of metallurgical progress, utilising a number of elements rarely used in alloy steel production at the time, and added to the retained knowledge of metallurgy at Cammell's research laboratories. In 1907, a second research team at Cammell, William Archbold Hartley and metallurgist Bedford Henry Deby patented a new method of producing armour remarkably similar to Wilson's compound armour from the 1870s.[52] Their compound steel armour was produced by first casting the back of the plate, and once solidified the front of the plate was cast directly onto it. This method of

[47] Trebilcock, Science, p.573.
[48] British Patent 8299/1903, pp.3-5.
[49] British Patent 8299/1903, p.5.
[50] British Patent 1,850/1903.
[51] British Patent 1,850/1903.
[52] British Patent 15,976/1907, p.2.

compound casting meant the two layers could possess different metallurgical compositions. The front of the plate contained 0.5-1% carbon, 1-3% of chromium, tungsten and molybdenum, and 2-6% nickel, while the back of the plate contained 0.1-0.3% carbon, 2-6% nickel, 0.75-3% chromium, and 0.25-1% vanadium.[53] The use of five different elements in the composition of the armour was unique among the Sheffield armourers. Incidentally, this would have increased the cost of producing armour using this method, and certainly played a part in preventing its introduction. While innovation was promoted by all armament companies, the cost implications involved with the introduction of any new product were carefully considered in relation to the potential of profits being made. Producing KC armour may have been difficult, but over time and with experience their production was progressively more efficient and cheaper, allowing greater profitability for the company.

None of the three designs highlighted went into production and developed beyond the patent stage yet all were utilising the most advanced techniques and experimental information related to metallurgy, creating new knowledge for future use by the research teams involved. Armour research at Brown and Cammell explored the use of a range of elements for the composition and treatment of alloy steels for armour, including tungsten, manganese, nickel, molybdenum, chromium, boron and vanadium. Tantalum can also be added to the list, used by Vickers for an experimental armour design in 1909.[54] Overall, the nature of spin-off at the two companies from armaments research was in the form of knowledge relating to the effect of these elements on the performance of steel, retained by the research teams involved for future utilisation for either commercial or armaments developments. Principally, this knowledge was derived from research dead-ends, demonstrating that the spin-off of new information from armaments research did not have to be from a finished product. Given the lack of success with the development of new alloy steels, future armour research would look to more practical solutions to counter the superiority of attack over defence.

By 1908 AP projectiles were able to successfully perforate and defeat KC armour when attacked at right angles to the plate due to the action of the soft steel cap placed over the point of the projectile. To counter this development, at

[53] British Patent 15,976/1907, p.3.
[54] British Patent 12,055/1909.

Brown Tresidder experimented with the use of two armour plates instead of one. His design would use the same thickness of armour as normal, but split into an outer decapping plate one quarter the thickness of the inner plate, with a controlled gap between the two. The use of two plates was not new, but maintaining an approximate relative thickness and separation between the inner plate and the outer decapping plate was novel.[55] The action of the outer plate would remove the projectile cap, reducing its ability to successfully perforate the inner plate. The design, however, did not go into production, possibly due to the need to produce and treat twice as many plates as usual, either doubling production times or requiring the expansion of facilities to produce KC armour. Nevertheless, this example shows that practical solutions rather than altering the composition of the material were beginning to be the basis of armour research and development.

The armour research at Brown again demonstrates how the continued refinement and development of armaments technology was tied to the work of a consistent research team, in this case Tresidder. The incremental improvements and advances made at the company predominantly built on his research, utilising path dependent sub-innovations.[56] Furthermore, Tresidder continuously speculated on future developmental needs for armour plate, with limited success.[57] The main outcome of armour developments beyond 1900 was in the production of metallurgical knowledge at the forefront of the industry, and of increasing benefit to civilian developments.

Overall, projectiles and armour were products which inherited the use of science and metallurgical knowledge, their productive origins based on major innovations in bulk steel, casting and forging. The desire to refine their performance saw the merging of armaments and metallurgical technique, the former providing the latter with ample opportunity for experimentation with alloy steel compositions and treatment processes. In return, armaments provided metallurgy with a broad information base, built on experiments and testing to understand the effect of a range of elements on the performance of steel, in many cases at the forefront of metallurgical knowledge and decades ahead of

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[55] British Patent 19,062/1908, p.4.
[56] See N. Rosenberg, *Exploring the Black Box* (Cambridge, Cambridge University Press, 1994), Chapter 1: 'Path-dependent aspects of technological change.'
[57] R.R. Nelson, 'Why Do Firms Differ, and How Does it Matter?' *Strategic Management Journal*, Vol.12 (1991), p.70.

commercial utilisation of such materials in alloy steels. This mutual development involved companies utilising established production methods at their works, combined with a growing application of scientific approaches to steel manufacture. However, from the early 1900s metallurgical knowledge began to be used to develop new armaments and commercial products based not on established techniques of steel production, like forging, casting and bulk steel processes were, but in the manipulation of the elemental content of alloy steels to improve their properties and performance.

Armaments and Metallurgical Developments

The potential utilisation of metallurgical knowledge to create a new armament product was realised by Robert Abbott Hadfield who, away from the development of projectiles, sought to exploit his knowledge and research into alloy steels for use in armour and armour plating. Introduced in 1904, ERA steel armour utilised a nickel-chromium alloy consisting of between 0.25% and 5% chromium, 0.25% to 7% nickel, and a low content of manganese up to 0.45%.[58] While previously armour had been forged, meaning little could be done to modify it after production, ERA steel armour could be cast, allowing complex shapes to be produced in a single piece.[59] This was a major step forward in armour plate manufacture, and allowed ERA steel to be utilised in gun housings, conning towers and other structures which had previously been defended by light armour. The Navy incorporated ERA steel into ship designs for this purpose, though Hadfield envisioned wider uses for the material. Believing the product provided greater resistance than KC armour, he foresaw that ERA steel could be used for capital ships and devised a means of producing 'joint-less armour' for naval vessels.[60] However, Hadfields did not possess the substantial production facilities to produce such armour in large quantities, nor was the company forward integrated into shipbuilding as an outlet for the product. Hadfield would have to look for a potential collaboration in the wider armaments industry.

In 1904, Hadfield sought an amalgamation with Armstrong as a commercial outlet for ERA steel. His proposal to Armstrong is summed up in a

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[58] British Patent 19,133/1906, p.5.
[59] Tweedale, *Steel City*, p.102.
[60] British Patent 14,706/1908.

letter from Stuart Rendel, vice chairman of Armstrong, to Sir Andrew Noble, chairman of the company[61]:

> It puts me flat on my back and is a bolt from blue! Hadfield is to become our largest share-holder, to have a seat on our board at a big salary, to draw £5,000 a year for twenty years, and we are to value his shares one-and-a-half times the value of his own… all this for a licence in England for a patent that may be worthless tomorrow! What a gamble![62]

This was an ambitious move by Hadfield. While Armstrong would gain a potentially lucrative, yet commercially untested patent, it was Hadfield who would gain the most from the arrangement. A seat on Armstrong's board would have placed him in the upper echelon of the country's armourers, a prospect which certainly appealed to his ego. However, he risked loosing the managerial influence his chairmanship of Hadfields gave him in a newly merged organisation. It is only possible to speculate on what advantages Hadfield saw for the amalgamation beyond a patent arrangement. As Armstrong's largest shareholder his wealth would have continued to grow and it is possible he anticipated ultimately becoming chairman of the company. Armstrong suggested a revised agreement in November 1907, in response Hadfield dispatched his directors Admiral Sir Archibald Douglas, who had previous links with Armstrong, and Colonel Sir Howard Vincent to correspond and meet with Noble.[63] By March 1908, negotiations had broken down, with Vincent and Douglas reporting back to the Hadfields' board:

> we entered into negotiations with Messers Armstrong Whitworth Ltd with a view to the amalgamation suggested by them. After several meetings

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[61] See K. Warren, *Armstrongs of Elswick: Growth in Engineering and Armaments to the Merger with Vickers* (London, Macmillan, 1989), Part 3: Difficulties and Adjustments, 1905-14 for more details on the internal development and management of Armstrong during this period. On the career of Noble, see p.33 in the same volume.

[62] Stuart Rendel to Sir Andrew Noble, 20 November 1907, quoted from G. Tweedale, 'Business and Investment Strategies in the Inter-War British Steel Industry: A Case Study of Hadfields Ltd and Bean Cars,' *Business History*, Vol.29, No.1 (1987), p.67. See also R.P.T. Davenport-Hines, *The British Armaments Industry during Disarmament* (Unpublished Thesis, University of Cambridge, 1979), p.179. A brief profile of Rendel is provided in Bastable, *Arms and the State*, p.231.

[63] SA, Hadfields Volume 93, Hadfields Board Minutes No.2., 1904-1936, 18 November 1907; M.J. Lewis, R. Lloyd-Jones, J. Maltby and M.D. Matthews, *Personal Capitalism and Corporate Governance: British Manufacturing in the First Half of the Twentieth Century* (Ashgate, Farnham, 2011), p.61.

we were informed that the Elswick board was not unanimous on the subject and that the matter must be dropped.[64]

With the failure of negotiations with Armstrong, Hadfield opted to find a somewhat less ambitious commercial arrangement for the licence of ERA steel patents with the Scottish shipbuilder Beardmore in May 1908. While not the type of amalgamation originally planned, the arrangement placed Hadfields in closer contact with the Vickers' group, and provided further benefits to the company.[65] This second attempt to gain a substantial return on ERA steel patents would be a much simple licensing agreement, which had benefits for both companies. Beardmore would gain an exclusive licence to six of Hadfield's ERA steel patents, covering the armour, its treatment, and a range of products.[66] Furthermore, Beardmore were restricted to manufacturing ERA steel items over 10 tons and beyond Hadfields' productive capabilities, and would pay half of their profits on these products back to Hadfields. In return, Hadfields would produce items under 10 tons, and pay Beardmore one quarter of their profits made from ERA steel products as an incentive to market the products.[67] The connection of Beardmore to Vickers also provided Hadfield with a path into negotiations to join the Steel Manufacturers Nickel Syndicate for the first time.[68] Their ultimate entry to the syndicate allowed Hadfields to purchase nickel at around £30 per ton less than market prices, which could reach £160 per ton. By the end of 1914 the company had saved £41,700 in the cost of nickel, a key material in the production of Heclon and Eron shells and ERA steel.

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[64] SA, Hadfields Volume 93, Hadfields Board Minutes No.2., 1904-1936, 6 March 1908.

[65] In 1902 Vickers purchased half the shares of Beardmore in an attempt to stifle the development of a potential rival in armour and gun manufacture. Trebilcock notes of Vickers' decision 'The first priority in the aftermath of the Boer War was to limit the competition which declining demand, and the State's professed intention of widening supply, threatened to produce. Scanning the horizon for the most formidable risks, Vickers lighted, probably accurately, upon Beardmores, and it was almost certain to prevent this concern from adding a powerful capacity and reputation to the government's plans that the board decided to acquire its large equity interest of 1902. C. Trebilcock, *The Vickers Brothers: Armaments and Enterprise 1854-1914* (London, Europa Publications, 1977), p.91. On Beardmore's expansion and possible links with Armstrong, see Warren, *Armstrongs of Elswick,* Chapter 14: A New 'Complete' Armament Firm: Beardmores of Parkhead, and Chapter 15: Armstrongs and Beardmore. For a general overview of Beardmore, see J.R. Hulme and M.S. Moss, *Beardmore: The History of a Scottish Industrial Giant* (London, Heinemann, 1979).

[66] SA, Hadfields Box 59, Hadfields Patents and Royalties, January 1918, p.42.

[67] SA, Hadfields Box 67, Folder of Correspondence Between Hadfields and Vickers, 14 May 1908.

[68] SA, Hadfields Box 59, Hadfields Patents and Royalties, January 1918, p.44; Boyce, 'Nickel', p.158.

Elsewhere in Sheffield Brown and Firth, as an extension of their 1902 share arrangement, looked to establish a joint research facility to use their combined metallurgical knowledge for commercial usage, established the Brown-Firth Research Laboratory in 1908 and appointed Harry Brearley as its first director.[69] Brearley had previously been manager of Firth's Riga Works, where he was involved in the production of projectiles for the Russian Government. The rationale behind establishing the facility was the unifying of both company's research staff and experience. In this regard, the Brown-Firth Research Laboratory became the repository of both companies' metallurgical knowledge, inherited from armaments experimentation and consisted of information regarding the metallurgical principles of armour and projectile developments, and the effect of various elements and treatments on the material performance of steel. From its opening, the Laboratory worked on the development of alloy steels and treatments, predominantly for commercial purposes and to support their customers' needs.[70]

Figure 2.4: The Brown-Firth Research Laboratory

[69] On Brearley's life and career, see G. Tweedale, *Giants of Sheffield Steel* (Sheffield, Sheffield City Libraries, 1986), pp.5-12, and Brearley's Autobiography, *Knotted String* (London, 1941).
[70] 'Thomas Firth and John Brown Ltd', *Ironmaking and Steelmaking*, Vol.24, No.3, 1997, p.215.

Despite the commercial focus of the Brown-Firth Research Laboratory, Brearley was also involved with armaments. As part of Firth's commitment to support their customers with the Brown-Firth Research Laboratory, Brearley was invited to a small arms factory in May 1912 to study the erosion of rifle barrels. Away from the technological advances in projectiles at their Gun Works, Firth were the only Sheffield armourer to produce steel barrels for small arms, supplied to the Royal Small Arms Factory at Enfield.[71] By 1913, Brearley was also engaged in research work regarding the erosion of the inner-tubes of large calibre guns and made a breakthrough with experiments related to steel with a high proportion of chromium. The material, which contained 12.8% chromium and 0.24% carbon, was initially referred to as rustless steel, and after further developments and refinements the material gained its more commonly used name, stainless steel. Brearley, somewhat dryly, commented in his autobiography that 'the people in authority…saw nothing of commercial value, and still less of scientific interest, in it.'[72] Despite this viewpoint, with hindsight we can see that the development of stainless steel was one of the most important spin-offs from armaments research, and one which provided a tangible product with a vast range of commercial uses. Ultimately, stainless steel failed to be utilised for gun barrels, with Brearley reporting that 'the use of the material for ordnance purposes, as originally intended, appeared to excite no interest.' While never used for gun barrels, the commercial exploitation of the material was exceptionally rapid, with the Portland Works in Sheffield producing stainless steel cutlery, under the guidance of Brearley, in 1914.

While stainless steel was initially seen as a novelty, information about the material quickly spread and by 1915 several companies in Sheffield, including Vickers and Hadfields, were producing the material, making patenting the innovation impossible in the United Kingdom. As Tweedale has suggested, such metallurgical knowledge spread quickly in the City.[73] While difficult to explore business networks, we can nevertheless from the case studies offered make some generalisations. It is probable that some knowledge developed by armament companies into alloy steels spread through informal networks in Sheffield as well as through formal patents and licences. To understand this

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[71] Kelham Island Archive (KIA), MNTF/015, Firth's Steel Department Reports 1896-1909. Between 1900 and 1909 Firths Steel Department produced 801 tons of small arms gun barrels.
[72] Brearley, *Knotted String*, p.123.
[73] Tweedale, *Steel City*, p.201.

process, the general means by which companies innovate in the armaments industry requires further exploration, through the advancement of a model of innovation. The connections between companies are also a key element of the industry, and from this the existence of an armaments-metallurgy-steel innovation system centred on Sheffield can be explored. [74]

Technological Development and Innovation Systems

By examining the common features of armaments development and experimentation from the previous case studies, it is possible to advance a model of how innovation occurred in the armaments industry, and how the outputs from this research were connected to the wider Sheffield industry through the concept of an innovation system. This model is demonstrated in Figure 2.5, and requires some further explanation. While each armament company innovated in their own way, related to the research team involved, they all worked with a comparable group of inputs and outputs to their research and development activities. With inputs, it is possible to group these into four areas. Firstly, the productive facilities of the company set the boundaries of what their team would research. No armament company supported research into an innovation they could not manufacture. These boundaries also forced research teams to experiment in a restricted manner. With armour, the high cost of both Harvey and Krupp furnaces meant that only innovations which utilised these facilities were explored, building on what the company could already manufacture.

[74] On innovation systems, see R.R. Nelson, 'National Innovation Systems: A Retrospective on a Study', *Industrial and Corporate Change*, Vol.1, No.2 (1992), pp.347-374; R.R. Nelson and N. Rosenberg, 'Technical Innovation and National Systems' in R.R. Nelson, *National Innovation Systems: A Comparative Analysis* (Oxford, Oxford University Press, 1993); W. Walker, 'National Innovation Systems: Britain' in R.R. Nelson, *National Innovation Systems: A Comparative Analysis* (Oxford, Oxford University Press, 1993); C. Freeman, 'The "National System of Innovation' in Historical Perspective', *Cambridge Journal of Economics*, Vol.19, No.1 (1995), pp.5-24; R. Lloyd-Jones and M.J. Lewis, 'Technological Pathways, Modes of Development and the British National Innovation System, Examples from British Industry 1870-1914', in L. Tissot and B. Veyrassat, *Technological Trajectories, Markets, Institutions, Industrialised Counties, 19th-20th Centuries: From Context Dependence to Path Dependency* (Bern, Peter Lang, 2001); D. Archibugi and J. Michie, 'Technological Globalisation and National Systems of Innovation: An Introduction', in D. Archibugi and J. Michie, *Technology, Globalisation and Economic Performance* (Cambridge, Cambridge University Press, 1997); D. Archibugi, J. Howells and J. Michie, 'Innovation Systems and Policy in a Global Economy' in D. Archibugi, J. Howells and J. Michie, *Innovation Policy in a Global Economy* (Cambridge, Cambridge University Press, 1999); G. Dosi, 'Some Notes on National Systems of Innovation and Production, and their Implications for Economic Analysis' in D. Archibugi, J. Howells and J. Michie, *Innovation Policy in a Global Economy* (Cambridge, Cambridge University Press, 1999).

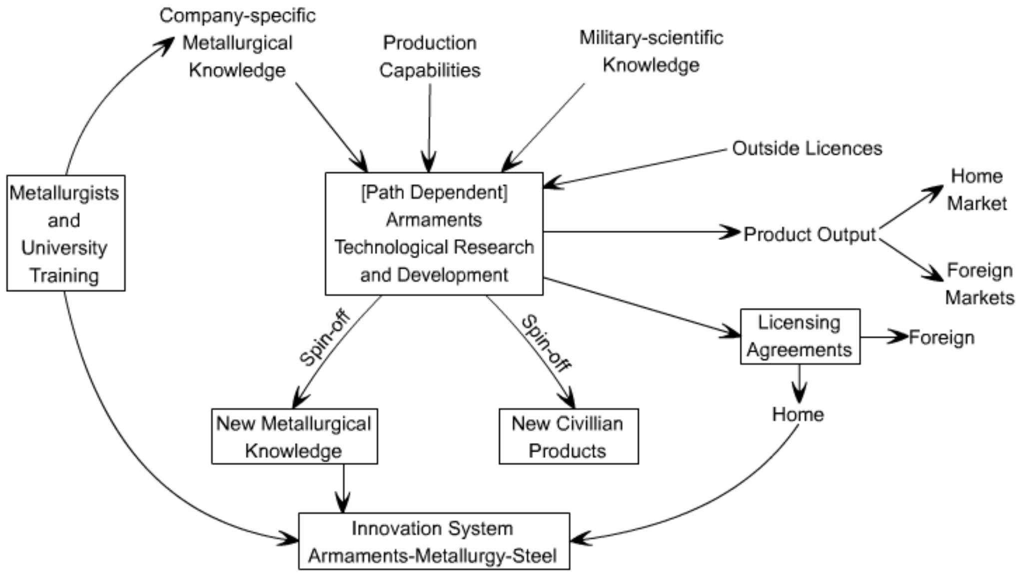

Figure 2.5: A model of armaments development in Sheffield

Secondly, company-specific metallurgical knowledge was a key aspect of the innovative process, either from a director-cum-technocrat such as Robert Abbott Hadfield, or brought into the company from outside sources such as University graduates, including those from the University of Sheffield's metallurgical programs. Trained university metallurgists also had a choice of which other steel companies they could work with in the Sheffield district, contributing to a wider armaments-metallurgy-steel innovation system. Broadly, knowledge of steel production and metallurgy affected how companies approached armaments developments. For projectiles, Firth stuck to what the company knew best in forging steel, Hadfields alternatively worked with cast steel. Military-scientific knowledge in the form of ex-military directors, was also influential in the innovative process, providing practical knowledge and experience from the use of armaments technology away from the testing ground and research laboratory, such as Captain Tolmie John Tresidder or Harry Bland Strange. Finally, the use of outside licences brought new armaments and metallurgical knowledge to the company, but how to utilise the knowledge to make further developments varied from team to team. New methods of production brought to a company in this way, such as KC armour, had to be integrated and understood by the research team involved so further developments could be attempted. However, when any refinements were made to an outside patent, the licences typically included a reciprocal arrangement whereby the new knowledge had to be communicated back to the original licensee free of royalties.

This combination of inputs influenced armaments research and development at each company. From the case studies presented, the use of sub-innovations to assist in the path-dependent development of armaments typically achieved the greatest results.[75] However, the nature of technological path dependence varied between companies and was perpetuated by the research teams involved. By building on prior research to develop new sub-innovations, solutions could be found quicker than a new research team being brought together for each issue. This way, tacit knowledge developed by the team from prior armaments research could be more rapidly utilised.[76] The research teams established by Hadfields, built around Robert Abbott Hadfield, Firth with James Rossitter Hoyle and later Harry Bland Strange, and Brown with Tolmie John Tresidder are examples of this. Their success in the development of projectiles and armour are testament to the value of path dependent technological research and their investigations into an ever increasing number of sub-innovations. Conversely, the changing teams at Cammell had less success and in some instances lagged behind the progress of their contemporaries.

The outputs from armaments research and development can be split between the successful output of a new design, and the by-products of armaments research grouped as spin-offs. For every armament company, the principal aim of any research was a product output, which could be sold to either a home or an overseas buyer. Typically this was very soon after the patent was granted and testing and approval were complete, though in some cases companies speculated on what future technological demands and requirements would be to varying levels of success. In these cases, some designs retained for future use did eventually go into production, though examples of this are rare. Dead-ends, where a product failed to go into production, were a common part of the innovative process for armaments. A second and equally common output of successful armaments research were licensing agreements with other manufacturers at home and overseas. As

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[75] See N. Rosenberg, *Exploring the Black Box*, Chapter 1: 'Path-dependent aspects of technological change.'

[76] For a discussion of tacit knowledge, see G.M. Hodgson, *Economics and Utopia: Why the Learning Economy is Not the End of History* (London, Routledge, 1999), pp.46-9.

demonstrated with projectile technology, this was a secondary means of profiting from armaments research, controlling the flow of technological knowledge from the company and maintaining a common technological level of the industry in a collusive fashion. These connections between companies also contributed to an armaments-metallurgy-steel innovation system.

Spin-off outputs from armaments research can be split into two parts, tangible commercial products and metallurgical knowledge. In some cases, the spin-off from armaments technological development resulted in refinements made to established civilian product lines at the same company, such as with the construction of rock and ore crushing machinery at Hadfields, or through the commercial exploitation of a new material such as stainless steel from the Brown-Firth Research Laboratory. Armaments-based and commercial-based metallurgical developments were part of a continuum, the two fields constantly able to draw on and influence each other in their experimental developments. The second element of spin-off was in the form of new metallurgical knowledge, armaments technological developments contributing to a broad information base related to the alloying of steels, treatments and productive methods from their extensive research and development activities. The effects of manganese, nickel, chromium, tungsten, molybdenum, boron, vanadium, and tantalum were all explored in relation to alloy steels and armaments in Sheffield in the two decades before the Great War. Some of these developments, such as Tresidder with tungsten alloys for armour, were decades ahead of equivalent developments in civilian metallurgy. The technological war between armour and projectiles, and consequently the rivalries created between armaments companies were the key factor in promoting the application of metallurgical knowledge to the advancement of armaments, and to the pool of metallurgical knowledge available to the members of an armaments-metallurgy-steel innovation system. This pool of metallurgical knowledge is what the inter-war special steel industry was built on in Sheffield.[77] With stainless steel, Brearley demonstrated how quickly a new product could be discovered and brought into commercial production in the city. Part of the pool of metallurgical information was derived from research dead-ends, the investigations which did not result in a viable sub-innovation or a design, product or patent that, while having positive

[77] The links between armaments, metallurgy and the emergence of the special steel industry in Sheffield are explored in Chapter 5.

attributes, failed to go into production and remained at the experimental stage. Nevertheless, dead-ends were a key part of generating new metallurgical knowledge in the industry. As Nelson highlights, knowledge is ‘won as a by-product of searching for new technologies’ and that ‘what succeeded and failed last time gives clues as to what to try next.’[78] The technological spin-off from research dead-ends which can be identified are uncovered from analysis of patent records, which is certainly assisted by the persistent culture of patenting in the industry before the Great War. However, it is highly likely that many more dead-ends were reached and more knowledge developed and documented in records which have not survived, if the information was recorded at all. While the armourers were secretive in their research and development, they all recorded explicit knowledge in their patent filings, which formed the basis of their licensing agreements. There may have been significantly more tacit knowledge retained by the research teams and their wider metallurgical staff which is impossible to uncover, and far more research and development took place with armaments than was ever recorded. Consequently, it is possible to view Hadfields, Cammell, Vickers and the Brown-Firth research laboratories, along with the university graduates, metallurgical chemists and staff working in them as repositories of the metallurgical knowledge created by each company as a spin-off from armaments research. A key part of this process of metallurgical spin-off was the recognition by the research teams and companies involved that the knowledge being created was important to their future research into both armaments and commercial alloy steels. Without this, it is possible much valuable information could be by-passed, while other metallurgists searched along similar lines for the next breakthrough in alloy steels.[79] It is also probable that as with stainless steel and Brearley’s research, knowledge spread quickly in the Sheffield steel industry, rapidly known to other companies, research facilities, staff and the university through informal connections between people rather than formal business links.

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[78] R.R. Nelson, ‘The Role of Knowledge in R&D Efficiency’, *Quarterly Journal of Economics* Vol.97, No.3 (1982), p.464.

[79] Nelson highlights that this type of knowledge is won in companies with a ‘proprietary interest not only in the new technique but also in the knowledge created to guide the next round of R&D. See Nelson, Role of Knowledge, p.466.

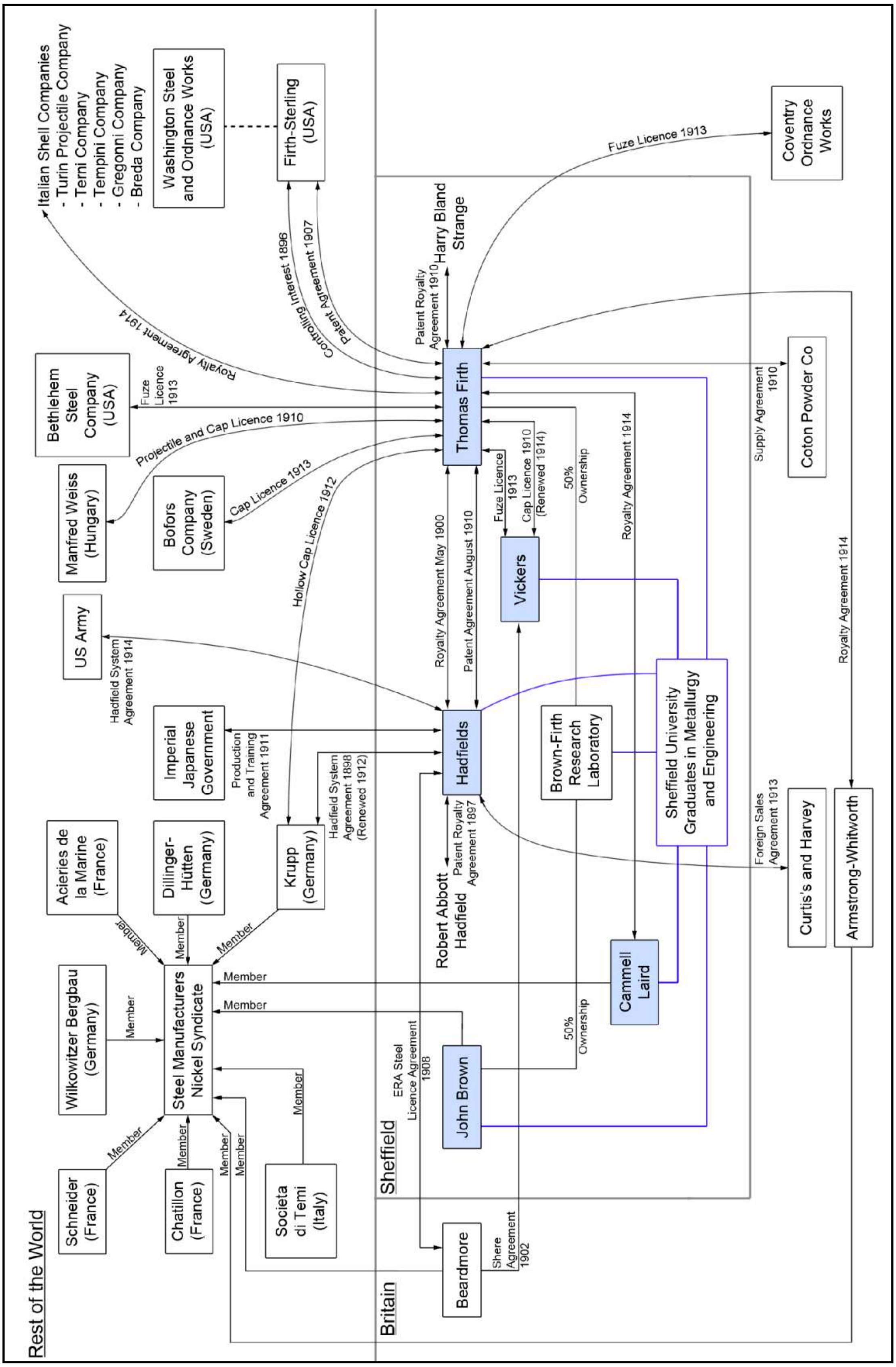

Figure 2.6: Technological linkages related to armaments 1914

The connections between people and companies were key aspects of innovation in Sheffield. The existence of an armaments-metallurgy-steel innovation system centred on Sheffield can be demonstrated by examining the intensity of technological linkages related to armaments and metallurgical research in the city in addition to the wider world as shown in Figure 2.6. While this principally shows the extent of licensing agreements for projectiles, in addition to the supply arrangements made with the SMNS, generally outside of Sheffield and Britain, the formal connections between technocrats, companies, and training provision in the city helped to build an important innovation system to support armaments and metallurgical technical development. These connections also aided in the spread of metallurgical knowledge between members of the industry. The group of companies which clustered in Sheffield were able to outperform companies in other locations, while continuing to allow individual companies to 'demonstrate sustained superior levels of performance.'[80] The network of Sheffield armaments companies can be described as a 'capsule' network, one which is 'relatively small in membership, self-contained and impermeable.'[81] In this regard, the network served a defensive mechanism, one in which technological innovation was maintained among those involved, yet prevented new entrants which could disrupt the structure of the industry. This compact network created links across the country and the rest of the world in order to flourish and fully exploit the technological innovations developed. The sharing of armaments technological knowledge among the Sheffield companies created a high-trust network from the reciprocal licences employed. Popp and Wilson have suggested that such high-trust networking 'could shade into collusive behaviours and attitudes, reducing the responsiveness of firms and districts.'[82] This was certainly the case with the armaments industry, and as will be demonstrated in Chapter 5 their responsiveness to the flood of orders placed with them in the early months of the Great War shows they were unprepared for the demands of wartime production.

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[80] S. Pinch, N. Henry, M. Jenkins and S. Tallman, 'From 'Industrial Districts' to 'Knowledge Clusters': A Model of Knowledge Dissemination and Competitive Advantage in Industrial Agglomerations', *Journal of Economic Geography*, Vol.3, No.4 (2003), p.375.

[81] A. Popp, S. Toms, and J. F. Wilson, 'Industrial Districts as Organisational Environments: Resources, Networks and Structures', *Management and Organisational History*, Vol.4, No.1. (2006), p.363.

[82] A. Popp, and J.F. Wilson, 'Districts, Networks and Clusters in England: An Introduction' in A. Popp, and J.F. Wilson (Eds) *Industrial Clusters and Regional Business Networks in England 1750-1970,* (Aldershot, Ashgate, 2003), p.15.

Conclusion

In Sheffield the production of armaments built on older productive methods and techniques in casting, forging and bulk steel production. All of these were based on rule of thumb methods with origins external to armaments production, but when utilised by the industry they can be seen as major innovations, commencing the path dependent nature of research. Thereafter, sub-innovations were utilised to refine the performance of a product, increasingly influenced by alloy steels and metallurgical developments, creating new metallurgical knowledge from the fusion of the two industries. The technological driving force in the industry was the continuous, unrestricted development of armour and projectiles which pushed the limits of alloy steel technology. As the knowledge available to research teams increased, new innovations based on the use of metallurgy, such as ERA armour and stainless steel began to be discovered and utilised. By the Great War, the major spin-off from armaments research was in the form of metallurgical knowledge, detailing the effect of various elements on the alloying of steels and new treatments and manufacturing techniques, in addition to each company possessing extensive research laboratories. The technological connections between companies in the Sheffield armaments industry can be seen as part of an armaments-metallurgy-steel innovation system, facilitating the sharing of knowledge and providing a defence against any new entrants to the industry. Overall, by 1914 the armaments companies in Sheffield were at the forefront of developments with armour and projectiles, making the city perhaps the most important centre for armaments technology and production in the world. Nevertheless, it was the commercial trading environment, not the research laboratory or testing ground, where such extensive research investments would be rewarded. As will be explored in the following chapter, dealing with a monopsonist home buyer presented unique challenges, and required the fostering of a number of special relationships with the British Government.

Chapter 3: Business, Marketing and Special Relationships - Armourers and the British Government 1900-1914

Before the Great War, Sheffield was the world centre of armaments technology. The four companies involved utilised metallurgical skill and knowledge to advance both armour and projectiles, in turn generating a pool of information regarding the scientific application of metallurgy. However, technological prowess was not a guarantee of generating profits from their research and the large number of patents emanating from the industry. As Warren has highlighted, 'the inventor must join with a manufacturer unless he is unusually well placed to begin production on his own account.'[1] Bastable has also suggested that we should not acknowledge technological innovation as business entrepreneurship, and that technology does not 'necessarily bring business success.'[2] Technological competence had to be coupled with the ability to supply the British Government. Vickers and Armstrong managed to supplement their duopoly of supply of gun mountings by sharing their technical knowledge in the early 1900s.[3] Any inventors involved in the industry had to be tied to a board of directors who understood how to exploit their technological position to generate orders and profits from the British Government. By examining the business record of the armaments companies, the value of their technological investment can be explored. A key element of managing any armaments company was the establishment and maintenance of a strong relationship with their home monopsonist buyer, against the backdrop of an oligopolistic market system.

This chapter utilises Trebilcock's notion of 'special relationships' existing between the state and private industry for the procurement of armaments.[4] This unusual market arrangement emphasised the British Government's preference for maintaining close connections with a small number of companies for the

[1] K. Warren, *Armstrongs of Elswick: Growth in Engineering and Armaments to the Merger with Vickers* (London, Macmillan, 1989), p.3.
[2] M. J. Bastable, *Arms and the State: Sir William Armstrong and the Remaking of British Naval Power, 1854-1914* (Aldershot, Ashgate, 2004), p.109.
[3] J. Singleton, 'Full Steam Ahead? The British Arms Industry and the Market for Warships, 1850-1914' in J. Brown and M.B. Rose, *Entrepreneurship, Networks and Modern Business* (Manchester, Manchester University Press, 1993), p247.
[4] See R.C. Trebilcock, 'A 'Special Relationship' – Government, Rearmament and the Cordite Firms', *Economic History Review,* Vol.19, No.2 (1966), pp.364-379; C. Trebilcock, *The Vickers Brothers: Armaments and Enterprise 1854-1914* (London, Europa Publications, 1977), pp.16-18.

procurement of armaments. The term special relationships is used for continuity with Trebilcock's work, though here 'special' is used only to signify an unusual and distinctive relationship rather than something exceptional for the companies involved. However, Trebilcock's work on the cordite industry views all the relationships the government maintained as principally equal in value and prestige to both procurement officials and private industry. Was this the case for the Sheffield armaments companies, or did a hierarchy of special relationships exist in the industry with some companies viewed as more special than others? This chapter will explore three key areas related to understanding if a hierarchy of special relationships existed prior to the Great War. Firstly, there will be an investigation into the nature of government spending with private industry, also known as the 'Trade', and how special relationships developed through the personal connections of ex-military personnel and members of parliament gaining directorships with armaments companies. This section will also highlight the issues which could arise if companies failed to toe the line of government officials. The final two sections will examine the business of armour and projectiles in turn, examining the ordering patterns of the Government with Brown and Cammell for the former, and Hadfields, Firth and Cammell with the latter, and also evaluates the value of technological investment by each company.

Special Relationships, Directors and Marketing

It has been well established that the business environment in which the armaments industry operated was one characterised by uncertainty.[5] The demand for armaments did not follow general trade cycles, predominantly sticking to 'their own rhythm.'[6] In this regard, armaments companies stood '*outside* the business cycle, probably a more dangerous position even than inside it.'[7] As demonstrated in Table 3.1, orders to private industry during the Boer War increased demand to a pre-War peak, with Army orders particularly large.[8] Orders to private industry declined after 1902, recovering around 1909

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[5] S. Pollard, and P. Robertson, *The British Shipbuilding Industry, 1870-1914* (Cambridge, Mass., Harvard University Press, 1979), Chapter 10: The Influence of the State; Singleton, 'Full Steam Ahead', p.229; Trebilcock, *Vickers Brothers*, pp.10-11.
[6] S. Pollard, *A History of Labour in Sheffield* (Liverpool, Liverpool University Press, 1959), p.224.
[7] Trebilcock, *Vickers Brothers,* p.12.
[8] On the Boer War, see T. Pakenham, *The Boer War* (London, Weidenfeld and Nicolson, 1979).

with the increased demands for naval weapons in the armaments race following the German naval scare.[9] Changes in both home and international politics could also affect procurement patterns and defence spending. The Haldane Reforms, which reduced the size of the Army from 1906 onwards, negatively affected the nature of army procurement from the trade, whereas the German Naval scare in 1909 promoted spending on new capital ship building in the following years.[10] As the technological development of the Sheffield Armaments industry attests to, Britain was principally a naval power, and as such orders to the trade were generally larger from the Admiralty than the War Office, as highlighted in Table 3.1.

Table 3.1: Allocation of Naval and War Office Orders to Ordnance Factories and the Trade 1899-1914 (£ms)

	Naval Orders			War Office Orders		
Year	**Ordnance Factories**	**Trade**	**Percent to Trade**	**Ordnance Factories**	**Trade**	**Percent to Trade**
1899-1900	1.4	1.0	42	1.9	3.6	65
1900-1901	1.8	1.5	45	2.6	11.6	82
1901-1902	1.7	2.0	54	2.2	9.8	82
1902-1903	1.4	1.6	53	1.7	5.3	76
1903-1904	1.3	1.5	54	1.5	2.7	64
1904-1905	1.6	1.4	47	1.2	1.6	57
1905-1906	1.3	1.3	50	1.4	2.7	66
1906-1907	1.3	1.2	48	1.2	2.7	69
1907-1908	1.2	0.8	40	1.1	1.4	56
1908-1909	1.1	0.8	42	1.2	1.0	45
1909-1910	1.3	0.9	41	1.0	1.1	52
1910-1911	1.3	1.4	52	1.0	1.2	55
1911-1912	1.3	2.3	64	1.0	1.5	60
1912-1913	1.4	2.7	66	1.1	1.8	62
1913-1914	1.5	4.8	76	1.1	1.2	52

Source: TNA, WO 395/1 to 3, Reports of the Director of Army Contracts 1899-1914.

[9] R. Lloyd-Jones, and M.J. Lewis, 'Armaments Firms, The State Procurement System, and the Naval Industrial Complex in Edwardian Britain', *Essays in Economic and Business History,* Vol.29, No.1 (2011), pp.23-39. See also C. Trebilcock, 'War and the failure of industrial mobilization: 1899 and 1914' in J.M. Winter, *War and Economic Development, Essays in the memory of David Joslin* (Cambridge, Cambridge University Press, 1975), p.142.
[10] See R. Lloyd-Jones and M.J. Lewis, *Arming the Western Front: War, Business and the State in Britain 1900*-1920 (London, Routledge, 2016), Chapter 2: The Road to War: the Edwardian Economy, and Military Preparedness; Singleton, Full Steam Ahead, pp.237-8.; Bastable p.163.

As these figures demonstrate, beyond the end of the Boer War army orders to the Trade generally declined, while those from the Navy increased annually from 1908-9. However, the figures for total orders to the trade demonstrate the entire purchasing habits of each department; by examining the figures for more specific products related to the Sheffield armaments industry a more accurate picture of the environment which Brown, Cammell, Firth and Hadfields operated emerges. Allocations for 'armaments', which in this regard referred principally to large guns and gun barrels, is show in Table 3.2. From this a greater disparity in expenditure to the trade between the two departments can be seen, the Admiralty heavily reliant on outside sources, with the War Office much smaller. These figures also demonstrate the difference in annual procurement of each department. The total orders for armaments from the War Office to both the Ordnance Factories and trade from 1905-1913 (£582,000) were less than the annual expenditure to the trade by the Navy from 1910 onwards.

Table 3.2: Allocation of Armament Orders to Ordnance Factories and the Trade 1905-1913 (£,000s)

	Naval Orders			War Office Orders		
Year	**Ordnance Factories**	**Trade**	**Percent to Trade**	**Ordnance Factories**	**Trade**	**Percent to Trade**
1905-1906	*No data*	*No data*	*No data*	88	10	11
1906-1907	*No data*	*No data*	*No data*	55	8	13
1907-1908	*No data*	*No data*	*No data*	68	5	7
1908-1909	*No data*	*No data*	*No data*	51	1	2
1909-1910	215	503	72	52	1	2
1910-1911	236	763	76	49	3	6
1911-1912	245	970	80	71	3	4
1912-1913	245	870	78	96	21	18

Source: TNA, WO 395/1 to 3, Reports of the Director of Army Contracts 1905-1913. In this regard Armament referred principally to orders for finished large guns and gun barrels.

An examination of projectile orders in the same period further demonstrates the greater reliance on the trade by the Navy, as shown in Table 3.3. While War Office orders were a greater proportion to the trade than for armaments, these were often for smaller calibre projectiles, typically not produced by Hadfields or Firth. In contrast, the Navy were significantly more reliant on the trade for projectiles, reflected in the increasing value of orders to private industry from 1909 onwards.

Table 3.3: Allocation of Projectile Orders to Ordnance Factories and the Trade 1905-1913 (£,000s)

	Naval Orders			War Office Orders		
Year	**Ordnance Factories**	**Trade**	**Percent to Trade**	**Ordnance Factories**	**Trade**	**Percent to Trade**
1905-1906	*No data*	*No data*	*No data*	302	65	18
1906-1907	*No data*	*No data*	*No data*	190	55	22
1907-1908	*No data*	*No data*	*No data*	221	65	23
1908-1909	*No data*	*No data*	*No data*	360	27	7
1909-1910	626	331	36	272	25	8
1910-1911	672	427	39	328	112	25
1911-1912	797	901	53	333	204	38
1912-1913	811	1,241	60	322	199	38

Source: TNA, WO 395/1 to 3, Reports of the Director of Army Contracts 1905-1913.

Overall, the Navy was more reliant on private industry than the War Office in the years prior to the Great War. These figures also support the notion that the armaments companies in Britain before the Great War were part of a naval-industrial complex.[11] One way in which the naval-industrial complex manifested itself was in the creation of 'special-relationships' between private companies and the government. The notion of special relationships was first highlighted by an anonymous trade journalist in *Arms and Explosives* under the name 'Cyclops', possibly alluding to a link with Cammell, which suggested that the government preferred 'a special relationship with a few firms so that it may reap the advantages which this offers.'[12] At the core of this was a preference by the Government to deal with a small number of companies for armaments procurement in a bid to strike a balance between price considerations and an assurance that all contracts would be satisfactorily completed to the required specifications.[13] This notion had been expanded by Trebilcock, who asserts that

[11] See Bastable, *Arms and the State*, Chapter 7: The Naval-industrial Complex; Lloyd-Jones and Lewis, 'Armaments Firms', pp.23-39. Warren has also suggested that Armstrong were part of the early development of a military-scientific-industrial complex in the late Victorian period. See K. Warren, *Armstrong: The Life and Mind of an Armaments Maker* (Berwick, Northern Heritage, 2011), pp.212-224.
[12] *Arms and Explosives*, May 1901, quoted in Trebilcock, *Vickers Brothers*, p.16.
[13] Trebilcock, *Vickers Brothers*, p.17.

‘the ‘special relationship’ reveals the two-way movement of influence: the government engineered the creation of capacity and the firms negotiated payment in orders for their obedient efforts.’[14] At the core of Trebilcock’s definition of a special relationship is an emphasis on the links between the procurement departments of the Admiralty and War Office and private industry. In contrast to Trebilcock, other approaches have utilised a broader definition of the Government which included the Cabinet and Parliament, but it is Trebilcock’s approach which provides the framework for the following analysis due to the limited availability of data regarding the Sheffield armaments industry’s links to other areas of Government.[15] While the notion of a special relationship refers to the entire industry, each armament company had their own singular special relationship with the government, which is shown by the analysis of the Sheffield case studies.

The most effective means of maintaining a special relationship with the government was with the use of directors with military and governmental backgrounds by companies in the industry. Bastable has suggested that the external relationships of the armaments firms were more important than their internal management structure, and that ‘success went to those who best managed relationships with the state.’[16] Singleton has also highlighted that ‘Firms believed that it was highly beneficial to secure a regular exchange of personnel between the public and private sector’ and that this facilitated the movement of influence between the two parties.[17] For example, in his discussion of warship builders, Singleton has suggested that they ‘needed to recruit officials who knew the Admiralty ropes, but by doing so they risked alienating those whom they were seeking to influence.’[18] Government officials often looked upon their former colleagues as being stolen by private industry, and at times were reluctant to deal with them. The choice of directors was also a difficult one for each company. A balance had to be struck between bringing to the company new technological knowledge, which as the previous chapters demonstrated could have a positive impact on their research and development capabilities, and new knowledge of future demands. Individuals who could bring

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[14] Trebilcock, Special Relationship, p.378; Trebilcock, *Vickers Brothers*, pp.16-18.
[15] Bastable, *Arms and the State,* p.241.
[16] Bastable, *Arms and the State,* p.229.
[17] Singleton, Full Steam Ahead, p.230, p.241.
[18] Singleton, Full Steam Ahead, p.242.

both were rare and highly sought after. New appointments, above all else, had to enhance the position of the company in the armaments industry. In his exploration of Vickers' management before 1914, Trebilcock has emphasised the collective excellence of their board of directors, stressing the complementary experience of the group to the success of the company, while highlighting that the group also contained much 'individual excellence.'[19] This balance between individual and collective excellence was one strived for by each company in the industry.

Table 3.4: Hadfields' Directors 1900-1914, and directors who continued 1914

	Appointed to Board	Office	Left Board
Robert Abbott Hadfield	1888	Chairman and managing director from 1888	Continued
Benjamin Freeborough	1888	Director	Died 1914
Alexander G.M. Jack	1897	Director, MD from 1905	Continued
Colonel Sir C. E. Howard Vincent (also shareholder)	1903	Director	Died 1908
General Sir Henry Brackenbury	1904	Director	Retired 1914
William Henry Dixon	1905	Director	Retired 1914
Henry Cooper	1905	Director	Continued
Admiral Sir Archibald L. Douglas	1907	Director	Died 1913
Lord Claude John Hamilton	1909	Director	Continued
Peter Boswell Brown	1910	Director	Continued
Major Augustus Basil Holt Clerke	1913	Director	Continued
Issiah Milne	1914	Director – head metallurgist	Continued

Source: SA, Hadfields Volume 7, OGM and EGM Minutes 1889-1919

At Hadfields, a progressive expansion of important outside appointments began in 1903 following a downswing in orders following the Boer War, under the direct guidance of chairman Robert Abbott Hadfield (see Table 3.4). The board of directors at the company agreed that Hadfield could enter into an arrangement with anyone he wanted as a director without their prior approval,

[19] Trebilcock, *Vickers Brothers*, p.145.

and that they would unanimously accept their appointment.[20] Consequently, some board members had previously been employed in other roles at Hadfields being appointed a director by the chairman. As a result of the hand picked nature of their appointments, the Hadfields' board was characterised by a high degree of loyalty, with exit only by retirement or death.[21] The first outside appointment in 1903 was Colonel Sir Howard Vincent, who was a personal acquaintance of Hadfield. A Conservative MP for Sheffield Central, Vincent was Hadfield's first link to Westminster and his informant in the House of Commons, giving Hadfield a link to the heart of Government. Vincent's appointment was important because of his link to Sir Henry Brackenbury, at the time Director General of the Ordnance at the War Office, whose tenure in the position was due to end in early 1904. Upon the request of his 'old friend' Vincent, Brackenbury came to Sheffield to inspect Hadfields' works and 'satisfied himself that he could take a seat upon' the board 'without the slightest fear that he would ever compromise that which was of greater value to him than anything in the world – his good name and reputation.'[22] Brackenbury joined the board in 1905 following his retirement from the War Office. Making his public debut at the 1904 OGM, Hadfield made no secret of the intentions behind his appointment, remarking that 'His [Brackenbury's] advice and his experience as regards war materials and his presence on the Board would be of the greatest possible assistance to them.'[23] Reiterating Hadfield's comments, Vincent also remarked that:

> There probably was no one, either in England or any foreign country, who had such a grasp of all the technical details connected with ordnance, and his experience, assistance and service would be very valuable indeed.[24]

With the appointment of Brackenbury, Hadfield was not only extending his connections to important business networks at Whitehall, but bringing to the

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[20] Sheffield Archives (SA), Hadfields Volume 51, Directors Private Minute Book 1904, 1918-1939, 18 November 1904.

[21] M.J. Lewis, R. Lloyd-Jones, J. Maltby and M.D. Matthews, *Personal Capitalism and Corporate Governance : British Manufacturing in the First Half of the Twentieth Century* (Farnham, Ashgate, 2011), Chapter 3 : Hadfields Ltd, Personal Capitalism, Boardroom Culture and Corporate Governance.

[22] *Sheffield Daily Independent,* 15 March 1904.

[23] *Sheffield Daily Independent,* 15 March 1904.

[24] *Sheffield Daily Independent,* 15 March 1904.

company important knowledge regarding projectiles to supplement his own technological developments.

The board was extended again in 1907 through the appointment of Admiral Sir Archibald Douglas, whose addition allowed the fostering of a mutually beneficial link with the Admiralty. At the time of his appointment, Douglas had been a member of the Ordnance Committee and from 1905 to his retirement in 1907 had been Commander-in-Chief at Portsmouth. Remarking in 1907 on the addition of Douglas and Brackenbury to the board, Vincent assured the shareholders that they 'would see that both as regarded the Army and the Navy the Board was as well equipped as it was possible for any Board to be.'[25] Following the death of Vincent in 1908, Lord Claud John Hamilton was appointed to the board at the 1909 OGM.[26] A conservative party member, Hamilton became MP for Kensington South in January 1910, gaining Hadfield a potential link to the House of Commons.[27] After Douglas passed away in early 1913, his seat was quickly filled by Major Augustus Basil Holt Clerke, who had an extensive knowledge of artillery and had previously worked as an inspector at the Royal Arsenal.[28] Similar to Brackenbury, Clerke brought knowledge regarding the practical use of ordnance to Hadfields and would become an important future influence on the company's projectile developments. Overall, Hadfield was a dictatorial figure, presiding over hand-picked directors and creating what he considered a strong link to, and a perception of influence over the Government in the decade prior to the Great War. Elsewhere in the Sheffield armaments industry, the links between companies and the government were less extensive, and in many cases their directorships were influenced by family considerations as much as the need to foster a special-relationship.

Two cases which illustrate a familial ethos of company directorships are those of Brown and Firth (see Tables 3.5 and 3.6). In each case, a high degree of stability is apparent, based around the leadership of the Ellis family at Brown,

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[25] *Sheffield Daily Independent,* 22 March 1907.
[26] SA, Hadfields Volume 7, OGM and EGM Minute Book 1889-1919, p.78, 22 March 1909.
[27] Hamilton also had business interests in railways. See *Sheffield Daily Independent,* 18 March 1910.
[28] G. Tweedale, *Steel City: Entrepreneurship, Strategy and Technology in Sheffield 1743-1993* (Oxford, Clarendon Press, 1995), p.261.

and the Firth family at Firth.[29] Both families had been at the centre of their respective companies since each moved to limited liability in 1864 and 1881 respectively. These two companies had a closer association from 1902 via a share exchange after which Brown controlled 7/8ths of the shares of Firth. Prior to the arrangement, Firth's shares were divided into 640 ordinary shares of £500 each with the eight members of the board, six of whom were Firth family members, controlling 276 of them at the end of 1902, with a further 300 shares held by the wider Firth family not directly associated with the business. In total, the directors and Firth family combined controlled 90% of the company's share capital.[30] After the share exchange, 200,000 new 6% preference shares of £1 each were allocated to the previous shareholders of Firth on a pro-rata basis to their former holdings.[31] As part of the agreement, Thomas, Mark and H. Branson Firth all retired from the board, replaced by Charles Ellis and Charles MacLaren from Brown. In return, Bernard Firth joined Brown, after being appointed to the long vacant position of chairman of Firth. John Sampson also joined Brown in 1904, completing an executive group of four directors which sat on both boards.[32] The number of family members on the board of Firth had been reduced from six to three by the end of 1903, but the business maintained the family culture which had evolved over several decades. Tweedale has suggested that prior to the exchange of directors with Brown, the 'family element of control was virtually dictatorial,' and most of the Firth family members on the board 'hardly emerge from the printed and manuscript sources.'[33]

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[29] On family business see R.A. Church, 'The Family Firm in Industrial Capitalism: International Perspectives on Hypotheses and History', *Business History*, Vol.35, No.4 (1993), pp.17-43; A. Colli, *The History Of Family Business 1850-2000* (Cambridge, Cambridge University Press, 2003).
[30] SA, X306/1/2/2/2, Firth EGM Meeting Papers, 19 November 1902, 10 December 1902.
[31] SA, X306/1/2/3/1/2, Firth's Directors Meeting Minutes, 23 December 1902, 29 December 1902 and 2 January 1903. 560 ordinary shares of £500 each in Firth were transferred to Brown, and 24,000 5% preference shares of £10 each and 90,000 ordinary shares of £1 each in Brown were transferred to Firth. Brown essentially held 7/8ths of Firth's ordinary shares, while Firth held a total of £330,000 of shares in Brown. Brown's share capital at the time was £2.5m.
[32] A. Grant, *Steel and Ships, The History Of John Browns* (London, Michael Joseph, 1950), p.51 states that Brown and Firth had 'many directors in common and great mutual advantages were enjoyed by both concerns from this arrangement. Both boards at that date can be congratulated on their far-sighted policy.'
[33] Tweedale, *Steel City,* pp.140-1.

Table 3.5: Brown’s Directors 1900-1914, and directors who continued 1914			
	Appointed to Board	**Office**	**Left Board**
John Devonshire Ellis	1864	Chairman from 1871	Died 1906
Charles McLaren (Baron Aberconway from 1911)	1883	Deputy chairman from 1897, chairman from 1906	Continued
Charles Edward Ellis	1884	MD from 1892	Continued
Captain Tolmie John Tresidder	1891	Director	Continued
L-Col J.G.S. Davies	1896	Director	Continued
J.E. Townsend	?	Director	Retired 1901
J. G. Dunlop	1899	Director	Resigned 1909
Bernard A. Firth	1903	Deputy chairman from 1906	Continued
John Sampson	1904	Director	Continued
William H. Ellis	1906	Director	Continued
Thomas Bell	1907	Director	Continued

Sources: Grant, A., *Steel and Ships*, SA, X308/3/1/1-3, Brown’s Annual Reports 1899-1902.

Table 3.6: Firth’s Directors 1900-1914, and directors who continued 1914			
	Appointed to Board	**Office**	**Left Board**
Lewis J. Firth	1881	MD from 1900	Retired 1909
Thomas Firth	1881	Director	Retired 1903
Mark Firth	?	Director	Retired 1903
Bernard A. Firth	1888	MD from 1900, chairman from 1903	Continued
H. Branson Firth	1890	Director	Retired 1903
E. Willoughby Firth	1893	Director	Continued
James Rossiter Hoyle	1893	MD from 1903	Continued
John Sampson	1899	Director	Continued
Charles E. Ellis	1903	Director	Continued
Sir Charles McLaren	1903	Director	Continued
Frederick C. Fairholme	1909	Assistant MD from 1910	Continued
Major Harry Bland Strange	1909	Director	Continued

Sources: SA, X306/1/2/2/1/1, Firth’s General Meeting Minute Book.

In addition to the use of family members at each company and their directorial overlaps, both Brown and Firth utilised external appointments to bring new knowledge to the board regarding armaments, and place them in closer contact with the government. At Brown, Tolmie John Tresidder was appointed in 1891 after a military career with the Royal Engineers, during which time he had become an expert on armour and ballistics.[34] Tresidder was supplemented by Lieutenant-Colonel Jasper Gustavus Silvester Davies, also of the Royal Engineers, who joined the board in 1896 and provided another link to the military and potentially important information networks. At Firth, James Rossiter Hoyle was appointed due to his independent knowledge of armaments[35], and Frederick Fairholme was added to the board in July 1909, after leaving Cammell in 1907, where he had been involved in armour and projectile research.[36] Finally, Harry Bland Strange, a former member of the Royal Artillery and gifted inventor joined in late 1909.[37] His work with Hoyle shaped the trajectory of armaments research at the company before the Great War and illustrates the value of armaments knowledge to the Firth's board of directors in comparison with metallurgical expertise. When Harry Brearley was invited from Firth's Russian works to head up the Brown-Firth Research Laboratory in 1908, a seat on the board of directors was not part of the arrangement. The Firth's board saw armaments experts and knowledge as more valuable to the strategy of the company, compared to viewing their metallurgical research laboratory as the driving force behind the technological future of the company. Overall these appointments were the extent of ex-military and armaments experts to the Brown and Firth boards prior to 1914. With the exception of Davies, these all brought knowledge and managerial skills related to armaments, but were somewhat limited in their links to the government. In comparison to Hadfields, Brown may be criticised for relying on two appointments from the 1890s to provide pertinent information up to 1914, while Firth overlooked the need to have links with the supply ministries until much later than their contemporaries. As shall be seen, there is a positive correlation between numbers of ex-governmental directors and the scale of orders received from the supply ministries. However, the boards of Hadfields, Brown and Firth demonstrated far greater stability than Cammell's directorship.

[34] Tresidder's career is profiled in Chapter 2 in relation to his developments with armour plates
[35] Hoyle's background is profiled in Chapter 1 in relation to his work with projectiles.
[36] SA, X306/1/2/3/1/3, Firth's Directors Meeting Minutes, 29 June 1909. Not willing to risk any issues due to his past at Cammell, Firth requested the approval of both the Army and Navy before offering Fairholme a position on the board. The scandal which led to Fairholme leaving Cammell is explored below.
[37] Strange's background is profiled in Chapter 1 in relation to his work with projectiles.

Table 3.7: Cammell's Directors 1900-1914, and directors who continued 1914

	Appointed to Board	Office	Left Board
Alexander Wilson	1864	MD to 1901, chairman 1900-1904	Died 1907
Charles D. W. Cammell	1879	Director	Retired 1904
Henry Watson	1880	Deputy chairman from 1900	Died 1901
Thomas William Jeffcock	1892	Director	Died 1900
Colonel William Sidebottom	1896	Deputy chairman from 1901, chairman 1904-5, 1909-10	Continued
James Duffield	c.1894-1897	Director	Retired 1904
Samuel Roberts MP	1896	Director	Continued
John Alfred Clarke	1898	Director	Retired 1906
Robert Whitehead	1901	Director	Continued
Albert G. Longden	1901	MD from 1902	Resigned 1907
Frederick C. Fairholme	1901	MD from 1902	Resigned 1907
Earl Of Wharncliffe	1901	Director	Retired 1905
Herbert Hall Mulliner	1903	Director	Retired 1905
John Macgregor Laird	1904	Deputy chairman from 1904, chairman from 1905-1907	Resigned 1907
Restel Ratsey Bevis	1904	MD from 1911-1912	Resigned 1913
Herbert Edward Wilson	1904	Director	Continued
Alexander Gracie	1905	Director	Continued
William Marshall Rhodes	1905	Director	Resigned 1907
Francis Elgar	1907	Chairman from 1908-1909	Died 1909
Arthur Daulby Wedgewood	1908	MD from 1908-1913	Retired 1913
Henry Edward Deadman	1908	Director	Retired 1913
Major Arthur Handley	1908	Director	Continued
Henry Westlake	1908	Director	Continued
William Lionel Hichens	1911	Chairman from 1911	Continued
George John Carter	1912	MD from 1912	Continued
James McNeil Allan	1913	MD from 1913	Continued

Sources: WA, ZCL/5/171, Cammell-Laird Register of Directors 1901-1913, ZCL/5/62, Cammell-Laird Register of Directors 1914-1924

In contrast to their counterparts in Sheffield, the board of Cammell demonstrates a low level of continuity, with a more fluid directorship. Between 1900 and 1914, the company was led by a total of 26 directors and five different Chairmen (See Table 3.7). An in-depth overview of the development of

Cammell's management in this period is provided by Warren.[38] From this it is possible to identify three stages in the development of Cammell's management before 1914. The first period to 1907 saw the company under the direction of three different Chairmen, Alexander Wilson, Colonel William Sidebottom and John Macgregor Laird. The Wilson family had been a part of Cammell since their move to limited liability in 1864, Alexander becoming chairman in 1900 after almost 40 years as managing director. After relinquishing his position as managing director in 1901, Wilson presided over the appointment of two successors in Albert Longden and Frederick Fairholme, the latter involved with Cammell's armaments research. A key appointment during this period was Samuel Roberts, who joined the company in 1896. His election as MP for Sheffield Ecclesall in 1902 gave the company a link to the House of Commons, a position he used to provide agitation for further orders to Cammell and the Coventry Ordnance Works, discussed in the following chapter. Trained as a barrister, Roberts was educated at Cambridge where he obtained a bachelors and master's degree, and was also a director of the National Provincial Bank. Wilson stepped down as chairman in 1904 but retained his directorship. He was succeeded by Colonel William Sidebottom, who had joined the company in 1896 after a military career and provided a valuable link to the Government in his position as MP for High Peak in Derbyshire until 1900. Sidebottom was succeeded by John Macgregor Laird in 1905, formerly chairman of Laird Brothers Shipbuilding Co before the merger between the two companies, who would resign just two years later.

The second phase from 1908 to 1910 saw the company initially under the guidance of Francis Elgar before his sudden death in January of 1909, after which Sidebottom once again took the chairmanship while the board looked for another replacement. Two of Elgar's appointments during his short tenure were Arthur Daulby Wedgewood as managing director in Sheffield at an annual salary of £5,000, and Major Arthur Handley, who provided the company with a new link to the military.[39] The third phase from 1911 began with the appointment of William Lionel Hichens as chairman. A former colonial administrator, Hichens was an unusual choice, a fact he personally acknowledged. He told the board at

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[38] See K. Warren, *Steel, Ships and Men: Cammell Laird and Company 1824-1993* (Liverpool, Liverpool University Press 1998), Chapter 8: Multi-plant Operations and Managerial Difficulties, 1900-14.
[39] Warren, *Steel, Ships and Men,* p.135.

his first interview that he knew nothing of armaments or shipbuilding, and 'their decision to recruit a man in his mid-thirties without previous industrial experience was quixotic.'[40] After his death, his wife recounted how she believed that Lord Selborne, a former High Commissioner of South Africa and First Lord of the Admiralty, and Lord Milner, with whom Hichens worked with in South Africa after the Boer War, were involved in influencing his recruitment.[41] If this was the case, it may be speculated that there were overtures from the Government to place someone desirable at the head of Cammell. Hichens was recruited at £3,000 a year, lower than the £7,000 Elgar received. Principally he facilitated the retirement of Wedgewood from his expensive position as managing director in Sheffield, replacing him with James McNeil Allan, formerly of the engineering and shipbuilding company Hawthorn Leslie. Warren has suggested that this appointment hinted at a future advance away from armaments due to Allan's reputation as a marine engineer.[42] At Birkenhead he recruited George John Carter, who had previously worked at Armstrong and was heavily involved in naval shipbuilding and design.[43] While the company had a changing leadership over the period, Cammell's understood the need to retain important connections to the military and government. Furthermore, these appointments aided in the accumulation of reputation and knowledge related to armaments and naval shipbuilding before the Great War.

Overall, with the four companies profiled Hadfields were most adept at securing ex-military and governmental personnel to their board of directors, with important links made to parliament, the army and navy. These appointments, facilitated by Robert Abbott Hadfield, brought with them important technical knowledge and the perception of influence over the supply ministries. Brown, Firth and Cammell also made important connections to the military and government, though these were small in number, relied on for much longer periods of time, and while some brought with them important armaments technical knowledge, they were supplemented by other non-military armaments experts. While broader in their scale of analysis, Pollard and Robertson have highlighted that the number of directors and important shareholders with

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[40] R.P.T. Davenport-Hines, 'William Lionel Hichens', in D.J. Jeremy, *Dictionary of Business Biography, Volume 3,* (London, Butterworths, 1985), p.199.
[41] Davenport-Hines, William Lionel Hichens, p.199.
[42] Warren, *Steel, Ships and Men,* pp.135-6.
[43] Warren, *Armstrongs of Elswick*, p.91 and p.96. Warren suggests that Carter's move to Cammell highlighted that Armstrong undervalued the skills of their managers as innovators.

connections with the government, House of Commons, Civil Service, and Service Ministries at Armstrong was 10, and Vickers-Beardmore had 11.[44] The difference in the scale of outside appointments begins to indicate the potential hierarchy of special relationship involved with the government, with Hadfields ahead of the other companies in the Sheffield armaments industry, yet still behind the much larger Vickers and Armstrong.

In addition to key military and governmental directors, the establishment of offices near the supply ministries was a key element of the business networks of all the Sheffield armament companies and provided the scope to further extend their boundaries. As Boyce and Ville suggest, 'the firm projects an influence into its environment and it is influenced by outside forces.'[45] Brown and Firth shared a London office at 6 The Sanctuary, on the doorstep of Parliament,[46] and Cammell maintained an office on Victoria Street close to Whitehall. London offices also put the Sheffield armourers in closer contact with foreign embassies and potential international customers. At Firth, Strange moved from Sheffield to London as representative director of the company in relation to artillery matters in 1911. He was also given an expense budget for entertaining guests at his London residence, in order to entice projectile orders from foreign governments.[47] Taking a different approach, Robert Abbott Hadfield moved to London in 1912 to the fashionable surroundings of Carlton House Terrace, 'so that he could become more involved in the scientific milieu of technical societies, which he relished so much, and – more importantly – be on the doorstep of the supply ministries for armaments orders.'[48] Hadfield was known as an active procurer of orders for his company through his connections with the Government ministries, and as his co-director Brackenbury commented 'from the inside of the War Office shield, he had learned through long experience that there was no one better in attacking that shield from the point of view of manufacturers wishing to get orders than Mr. Hadfield.'[49] It is perhaps not surprising then that Hadfield located his London home at 22 Carlton House Terrace, just a short walk from Whitehall. Most significantly, Hadfield removed

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44 Pollard and Robertson, *British Shipbuilding Industry*, p.222.
45 G. Boyce and S. Ville, *The Making of Modern Business*, (Basingstoke, Palgrave, 2002), p.25.
46 SA, X306/1/2/3/1/4, Firth's Directors Meeting Minutes, 29 April 1913. Firth paid for one third of the office, Brown two thirds after taking out a 21 year lease in 1913. Incidentally, the office was at the opposite end of Whitehall to Sir Robert A. Hadfield's residence at Carlton House Terrace.
47 SA, X306/1/2/3/1/4, Firth's Directors Meeting Minutes, 28 November 1911.
48 Tweedale, *Steel City*, p.261.
49 *Sheffield Daily Independent,* 15 March 1904.

the privilege of receiving Government orders from Hadfields' London Office at Norfolk House, Laurence Pountney Hill, and insisted that all Government orders be filed through the offices he established at his home.[50] No longer would Hadfield be reliant on employees for information about forthcoming orders. Under this arrangement he would receive information first-hand, and all Government officials would have to deal with him personally.

Another key aspect of the special relationships between private industry and the government was in the marketing of armaments. This incorporated the personal connections established with directors and London offices, but instead of emphasising the capability or branding of a product, the reputation, reliability, and to borrow from Trebilcock's definition of special relationships, 'obedient efforts' of each company involved were also under consideration.[51] As has been demonstrated in the previous chapters, the technological developments and relationships built in the industry meant that the performance of armour and projectiles from each manufacturer were broadly comparable. Furthermore, while branding such as Heclon, Eron and Rendable were used by the projectile manufacturers, this was principally for use internally to differentiate between products, and for marketing to foreign customers.[52] What mattered most was a continued maintenance of their capabilities in accordance with what was expected from them by the Government. Nevertheless, despite the fostering of special relationships between each company and the Government, they could still fall foul of the War Office and Admiralty. The case of Cammell in 1906-7 demonstrates that the government retained control over their associations with private industry, and that special relationships and goodwill built up over the course of years could be swept away rapidly for non-compliance with the strict rules and regulations laid down to contractors. The state may have been reliant on the armourers for technological advancement, but the companies were more dependent on the government for orders, and maintaining their place on the

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[50] SA, Hadfields Box 57, War Work Done at Sir Robert Hadfield's House, 22 August 1918, p.1.

[51] Trebilcock, Special Relationship, p.378; On domestic marketing also see R.P.T. Davenport-Hines, 'The British Marketing of Armaments 1885-1935' in R.P.T. Davenport-Hines, *Markets and Bagmen: Studies in the History of Marketing and British Industrial Performance 1830-1939* (Aldershot, Gower Publishing, 1986), pp.157-165.

[52] For examples of Hadfields' and Firth's use of brands with armaments marketing, see Sheffield City Library (SCL), Thomas Firth and Sons, *Projectiles Charged and Ready for Firing*, 1912, and *The Hadfield System as Applied to War Materials*, n.d., probably 1911. Foreign sales are discussed in the following chapter.

Admiralty and War Office procurement lists, suggesting a power relationship favouring the supply ministries in their network of special relationships.[53]

At Cammell problems began in November 1906, when the chief inspector at Woolwich communicated to Fairholme, the managing director in Sheffield, allegations concerning the quality of products manufactured at their Grimesthorpe works. Investigations took place in April 1907 which highlighted deficiencies in some Government products from Grimesthorpe, but the details of this were kept secret and were known only to the chairman Laird and the managing director Longden. A special board meeting was called in September, by which time it was clear that there were serious problems at the works.[54] The company was removed from the War Office list of contractors on 16 September, and the Admiralty list on 7 October 1907 and strict conditions were insisted upon by both departments before Cammell was reinstated as a Government contactor. They needed to reconstruct the directorate under a new chairman, remove the managing directors from Grimesthorpe, and prosecute those involved in the scandal at the company.[55] With no alternative, Laird, Longden and Fairholme resigned. The lack of Government orders thereafter shows how reliant the company had been on armaments for their financial prosperity. Losses were made in 1907 and 1908, and Cammell paid no ordinary dividend for five years. The company was pressurised by the government to change and dutifully complied, the failure to do so potentially ruinous. The board was reconstructed under the guidance of a new chairman Francis Elgar, former director of Her Majesty's Dockyards and managing director at Fairfields.[56] Four new appointments to the board were made in 1908, and in February Elgar requested full restoration to the list of Admiralty and War Office contractors. One of his main concerns was that no foreign governments would give them work until their full restoration to the War Office and Admiralty lists.[57] This again gave the Government the upper hand, as it was impossible for Cammell to supplement lost business with orders for overseas customers. On 25 March 1908, the Admiralty placed an 'important' order for armour with the company, and fully restored them to their list on 1 April, followed by the War Office on 2

[53] Singleton, Full Steam Ahead.
[54] See Warren, *Steel, Ships and Men,* pp.128-130 for a more detailed exploration.
[55] The National Archives (TNA), BT 13/44/5, E.W. Ward to Cammell Laird, 26 October 1907.
[56] Warren, *Steel, Ships and Men,* p.130.
[57] Warren, *Steel, Ships and Men,* p.131.

April.[58] Upon restoration, E.W. Ward at the procurement department of the War Office issued Cammell with a stern warning:

> This decision is given on the understanding that the severance of the connection between your firm and all the late officials of the Company who have been discharged or have received notice to leave in connection with the disclosures of improper practices is permanent and final.[59]

Effectively, there would be no second chances. Two conclusions can be drawn from Cammell's experience in what was known as the 'list scandal'. Firstly, in the network of special relationships between the Government and private industry, the Government held a more powerful position than the companies on their procurement list. They could choose not to use a company due to irregularities, the consequences potentially ruinous to any armaments manufacturer due to their heavy reliance on Government orders for profitability. In this regard, Cammell were used as an example to warn other armament companies that the Government was in control of their relationships, though with the small number of suppliers for heavy armaments it is unlikely that Cammell would have been allowed to collapse. Secondly, Cammell's experience demonstrates that being a supplier for the Government was the paramount requirement to enable access to the international armaments market. For foreign orders, the most essential marketing tool was being a supplier for the British Government. As will be explored in the following chapter, the use of international markets as part of a multi-faceted corporate strategy was an important defensive mechanism used by the armaments industry to counter the uncertainty in their home market.

The potential hierarchy of special relationships can be further explored by examining the business of each of the four Sheffield armaments companies, their strategies for securing orders from the British Government, and evaluate the importance of their investments in armaments technology. The following two sections will explore the business of armour and the business of projectiles in turn, the allocation of orders for each product having previously been

[58] Warren, *Steel, Ships and Men,* p.131; TNA, BT 13/44/5, Admiralty to Secretary of Board of Trade, 1 April 1908. See also TNA, WO 395/2, Director Of Army Contracts Report 1908.
[59] TNA, BT 13/44/5, E.W. Ward to Cammell-Laird, 2 April 1908.

overlooked in favour of exploring the shipbuilding industry with Vickers and Armstrong as case studies.

The Business of Armaments: The Armour Manufacturers

Armour was indelibly linked to the cyclical demands for warships, which consequently affected each manufacturer's efforts to maintain their works at full capacity and maintain profits on outputs. For Brown and Cammell, their ability to secure orders was made increasingly difficult by efforts to control the market by Vickers and Armstrong. In 1903 they came to an agreement with the Admiralty to limit naval gun orders to the two companies, so long as no other competitor could produce a superior product. This was followed by an attempt to force the Admiralty to order armour and guns as a package, limiting supply for new warship building to only companies which could manufacture both.[60] While not entirely successful due to the opening up of supply by the procurement departments, this did force Brown and Cammell to commence gun manufacture at the Coventry Ordnance Works, discussed in the following chapter. Overall, this made an already difficult trading environment more taxing. One key issue was that all of the armour for a ship was not ordered together. Instead test plates were required to prove their resistance, and consequently the armour manufacturer had to convince the buyer of their competence to produce before the armour for a whole ship was ordered. *The Engineer* summarised the ordering pattern of armour as follows:

> The British system of Admiralty control over armour plate manufacture is, for each order or series of orders, to subject to firing test a preliminary sample plate made under the direct supervision of the Admiralty overseers, and, if this sample is satisfactory, to order a number of plates to be made like it, also under direct supervision. The advantage of this system is that the Government officials have, and fully exercise, the right to watch and check the manufacture in all its details and at all stages.[61]

This acquisition process meant that maintaining accuracy in the production and treatment of armour was essential. Strict supervision of this kind obviously led

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[60] Trebilcock, *Vickers Brothers*, pp.94-5. Vickers and Armstrong also shared gun designs from 1902, and came to a market sharing agreement which covered the entire globe in 1906. See C. Trebilcock, 'Legends of the British Armament Industry 1890-1914: A Revision, *Journal of Contemporary History*, Vol.5, No.4 (1970), p.13.

[61] *The Engineer*, 23 August 1901, p.204.

to frustrations over delays in ordering, but there were also grievances by manufacturers over the method of payments from the Admiralty, which reduced stocks of working capital. After contracts had been agreed between the manufacturer and Admiralty, payments were made as manufacture progressed. The first 45% was paid once the plate was rolled or pressed to the required thickness, had passed the required metallurgical analysis, and was face treated and carburised. A second 45% was paid after hardening and the plate subsequently bent, machined, drilled and finished at the works. The final 10% was paid once the plate arrived at the shipbuilders and been approved.[62] In essence, maintaining an efficient works and timely output was paramount to ensuring a consistent payment for armour orders.

Table 3.8: Cammell's Sheffield Works (Cyclops, Grimesthorpe, Penistone) Invoiced Output, Profit and Dividends 1900-1913

	Sheffield Works (£,000s)		All Cammell Business	
	Commercial (Percentage)	**Armour, Cyclops West Forge (Percentage)**	**Profit or Loss (£)**	**Ordinary Dividend (%)**
1900	2,525 (72)	970 (28)	260,015	17.5
1901	2,419 (74)	871 (26)	201,403	15
1902	2,367 (86)	376 (14)	144,724	10
1903	2,205 (83)	444 (17)	144,670	7.5
1904	1,745 (85)	303 (15)	185,730	7.5
1905	2,158 (85)	373 (15)	231,806	10
1906	2,508 (82)	567 (18)	273,780	10
1907	2,798 (88)	372 (12)	-1,617	2.5
1908	1,623 (87)	237 (13)	-152,133	Nil
1909	1,416 (86)	235 (14)	50,714	Nil
1910	967 (62)	589 (38)	218,836	Nil
1911	1,039 (62)	647 (38)	120,962	Nil
1912	1,166 (64)	643 (36)	144,988	Nil
1913	1,320 (65)	724 (35)	174,126	2.5

Sources: WA, ZCL/5/54, Final Company Accounts 1910-1913. Note: Tweedale erroneously lists Preference, rather than Ordinary Share dividends for 1910-1912 in *Steel City,* pp.124-125.

[62] SA, X308/1/3/1/3, Brown's Secretary's Copy Letter Book No.6., Elias Middleton to Alfred Tongue, 12 August 1912. Tongue was an employee with W.B. Peat & Co., a London based accounting company which was investigating the costs of armour production.

By examining the business of both companies it is possible to demonstrate their ability to maintain profitability from armour production in the years before the Great War. At Cammell, two phases can be identified with their armour business, demonstrated in Table 3.8. Firstly, from 1900 to 1907 the size of their dividend was linked to the amount of armour produced at the company, the two rising and falling in tandem. However, there were years of lower demand such as 1902, which showed a decline in armour sales followed by the product representing a decreased proportion of the works output until 1907. This was lower than Brown, where armour averaged around 40% of their yearly invoiced output. Cammell were less reliant on selling armour for their profitability due to the commercial output of the company from their three Sheffield works, and commercial shipbuilding undertaken at Birkenhead. Secondly, Cammell's decline from 1908 to 1913 is a direct result of being dismissed from the Government procurement lists and their reduced reputation in the international market for armaments. During this period the company made significant losses, recorded no dividend payments for five consecutive years, and only returned to paying dividends in 1913. Once armour orders were restored, from 1910 their production was around 40% of the works output, with Cammell's commercial output shrinking during this period. After his appointment in 1911, Hichens noted that he saw the company as 'like an inverted pyramid standing not on its base but on its apex…so long as we continue to depend on one thing for our profits, our foundations will always be insecure.'[63] Overall, Hichens saw the relative value of armaments, but as part of a broadening of trade and an increase in commercial output.

By examining the profitability of Cammell's armour production the flexible returns from the product are apparent, demonstrated in Table 3.9. The decade began with large sales and profitability, followed by a decline in the size and returns from armour between 1906 and 1908. As orders increased their rate of profit fluctuated, before stabilising in 1911. By comparison, between 1911 and 1913 the profit on commercial outputs at the Cyclops Works averaged between 8 and 10%, while armour returned a minimum of 33% profit. This indicates that the profits from armour were related to economies of scale and the growing experience and expertise of their trained staff at the Cyclops Works West

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[63] Warren, *Steel Ships and Men*, p.135.

Forge. This is further exemplified in Table 3.10: between 1911 and 1914 the average cost of producing armour continually declined at Cammell. By the Great War, armour manufacture at the company was increasing efficient.

Table 3.9: Cammell's Profits on Armour Sales at Cyclops Works West Forge 1900-1913

Year	Armour Sales (£,000s)	Armour Profit (£,000s)	Rate Of Profit (%)
1900	970	289	30
1901	871	267	31
1902	376	175	47
1903	444	166	37
1904	303	121	40
1905	373	73	20
1906	567	83	15
1907	372	37	10
1908	237	41	17
1909	235	95	40
1910	589	159	27
1911	647	212	33
1912	643	217	34
1913	724	273	38

Sources: Calculated from WA, ZCL/5/54, Final Company Accounts 1910-1913, ZCL/5/127, Private Accounts to 1915, SA, ESC Box 192, Sheffield Plant and Sales details 1910-1917. Note that for 1908 and 1909 the profit figure is for all the Cyclops Works, not just the West Forge.

Table 3.10: Cammell's Output Of Armour Over 2" thick, West Forge Cyclops Works 1911-1914

Year	Output (Tons)	Total Cost (£,000s)	Average Cost Per Ton (£)
1911	5902	582	99
1912	6055	582	96
1913	6701	630	94
1914	5222	479	92

Sources: Calculated from WA, ZCL/5/54, Final Company Accounts 1910-1914.

By comparison Brown had a greater reliance on armour for their overall profitability, demonstrated in their business record in Table 3.11. From 1900 to 1905, more than half of the output of the Atlas Works was armour plate with a high of two thirds in 1901-2, reflected in the dividend declared in those years. In this period the relationship between profits and armour output is broadly relational, though the figures for 1901-2 indicate that returns on armour production were declining at the company. In 1905-6 the commercial output of Brown continued to expand with armour falling to its lowest output of the decade, though profitability expanded at the company. Brown's commercial business continued to grow up to 1913-14, in conjunction with expanding armour outputs and profits from 1909-10.

Table 3.11: Brown's Atlas Works Invoiced Output, Profit and Dividends 1900-1914

	Atlas Works (£,000s)		All Brown's Business	
	Commercial (Percentage)	**Armour (Percentage)**	**Profit (£)**	**Ordinary Dividend (%)**
1900-1901	361 (35)	657 (65)	440,393	20
1901-1902	325 (33)	657 (67)	232,789	15
1902-1903	*No data*	*No data*	185,750	10
1903-1904	299 (40)	446 (60)	159,109	8 1/3
1904-1905	340 (43)	445 (57)	198,936	8 1/3
1905-1906	410 (69)	188 (31)	223,881	10
1906-1907	456 (59)	322 (41)	234,237	10
1907-1908	462 (58)	339 (42)	218,405	10
1908-1909	388 (56)	301 (44)	204,896	7 1/2
1909-1910	515 (60)	342 (40)	202,017	7 1/2
1910-1911	614 (57)	454 (43)	212,523	7 1/2
1911-1912	650 (55)	531 (45)	227,109	7 1/2
1912-1913	775 (60)	526 (40)	271,901	7 1/2
1913-1914	781 (59)	541 (41)	377,498	10

Sources: Calculated from SA, X308/1/2/1/3/1-10, Brown's Managing Directors Reports 1905-1914; SA, ESC Box 280, Brown's Managing Directors Reports No.8.;Tweedale, *Steel City*, pp.124-125. Brown's financial year ran April through to March the following year.

Essentially, from 1905 onwards Brown's payment of an annual dividend to their shareholders was less reliant on their armour sales. The increased steel and marine forging requirements for their expanding shipbuilding interests on the Clyde facilitated a move away from relying solely on armour production and provided an outlet for their expanding commercial steel and forging capacity. This was a clear break from their decade's long reliance on armour as the foundation of their financial strength. At the 1907 AGM, Brown's chairman Sir Charles Mclaren commented that in 1884 when he joined the company they were entirely dependent on armour-plate and coal for profitability.[64] This change in the diversity of Brown's business continued up to the Great War, and in 1914 the directors commented that it was:

> '…gratifying to note that a very large part of the profits in the Atlas Works had been derived not so much from armaments work as from general commercial orders connected very largely…with their great shipbuilding enterprises.'[65]

This is not to suggest that armour was no longer an important part of Brown's business, but as the demands for armour were inconsistent to broaden the company's operations was strategically important to maintain continued financial stability. The cyclical nature of armour orders at Brown can be explored in Table 3.12.

Table 3.12: Summary of Brown's Armour Orders 1904-1914

Year	Total Armour Orders (£)	Largest Month Total (£)	Average Monthly Total (£)	Number Of Months With Orders Over £10,000
1904	501,800	298,485	41,817	2
1905	22,269	5,737	1,856	0
1906	766,545	368,618	63,879	4
1907	8,237	3,779	686	0
1908	320,455	288,776	26,705	2
1909	350,663	169,900	29,222	3
1910	806,932	274,350	67,244	6
1911	536,424	249,605	44,702	6
1912	661,138	245,298	55,095	6
1913	856,273	611,002	71,356	4
1914 (To July)	347,410	287,576	49,630	3

Source: Calculated from SA, X308/1/2/1/3/1-10, Brown's Managing Directors Reports 1905-1914

[64] Tweedale, *Steel City*, p.126.
[65] *The Times*, 1 July 1914, p.20.

By examining 1904 to 1908 the inconsistent demand for armour is apparent, with some single monthly orders accounting for the majority of the year's total, while in other years few orders were recorded. A different picture is shown from 1909 to 1914, with orders more consistent but at times annual totals were principally derived from a single month of orders. Those received in June 1913 for over £600,000 of armour made up 71 percent of the total for the year. Essentially, British Navy orders could not be entirely relied upon to keep Brown's armour shops occupied, with the company actively seeking foreign orders to supplement Admiralty requirements, as explored in the following chapter. It is also apparent that Brown was principally a naval supplier; the only orders from the Army during the period 1904-1908 were for gun forgings, totalling £35,721.[66] In the same period, Admiralty orders for armour totalled over £1.6million, 98% of Brown's total armaments output. Beyond 1908, aside from orders received from the Coventry Ordnance Works, Brown's armaments production was entirely devoted to naval applications. Brown's reliance on armour required the company to maintain production efficiency, and consequently maintain the profits derived from their production, as explored in Table 3.13.

Table 3.13: Brown's Armour Production Costs 1906-1911

Year	Average Selling Price (£ per ton)	Cost (£ per ton)	Profit (£ per ton)	Rate of Profit (%)
1906-1907	103	85	18	17
1907-1908	114	94	20	18
1908-1909	107	86	21	20
1909-1910	103	82	21	20
1910-1911	101	70	31	31

Source: SA, X308/1/3/1/3, Secretary's Copy Letter Book No.6., Alfred Tongue to Charles Ellis, 28 August 1912.

Between 1906 and 1911 Brown's armour plant was increasingly cost effective, as selling and production prices declined while profits per ton continued to grow. As part of an Admiralty exploration into the costs of armour, the data in Table 3.13 had been prepared on Brown's behalf by Alfred Tongue of W.B. Peat & Co, a London based accounting company, who also worked with

[66] Calculated from TNA, WO 395/1-3, Director Of Army Contracts Reports 1902-1909.

Armstrong, Cammell and Vickers. As Tongue had access to the cost data of other armour manufacturing companies, he highlighted to Brown that he was 'sorry to say that your figures are likely to show the lowest cost and the highest profit for 1911 as compared with the other makers.'[67] By focusing on the production of armour Brown had become the most efficient producer in the country, yet were drawing what would have been viewed by the Admiralty as an excessive profit. Had their costs been higher, they would have been justified in charging more. The Navy may have been reliant on the trade to produce what they required, but they did not want to pay disproportionately more to a company than what they considered appropriate. Even with their low costs and proven ability with armour, Brown's relative position in the industry declined before the Great War due to changing armour requirements.

In 1911 Brown's armour shops were extended as orders were anticipated for up to 40,000 tons of armour from the Admiralty and foreign customers, with an expenditure of £60,000 authorised by Brown's Works Committee.[68] An increase in orders two years later led to a further extension of the works, with new Krupp and Harvey treatment furnaces installed at a cost of £15,000.[69] However, these extensions failed to keep Brown at the forefront of the armour business. In early 1914 Charles Ellis reported to Brown's Works Committee that with increasing demand for thicker plates, the company was having serious problems treating armour. Furthermore, it was reported that with their continued issues at their armour plant, Brown risked 'rapidly falling into the fourth position in the trade as to output' due to their increasing difficulty at maintaining the required quality.[70] While being an armour manufacturer could produce profitable returns, each manufacturer was required to maintain their capabilities in line with the requirements of the Admiralty. In order to satisfy the new requirements, Brown's Works Committee sanctioned a further £100,000 of extensions, with much of the Atlas Works rearranged as a consequence. At the same time, the Committee highlighted that 'every effort should be made to retain and expand

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[67] SA, X308/1/3/1/3, Brown's Secretary's Copy Letter Book No.6., Alfred Tongue to Charles Ellis, 28 August 1912.
[68] SA, X308/1/4/1/1/1, Brown's Works Committee Minutes, 24 July 1911.
[69] SA, X308/1/4/1/1/1, Brown's Works Committee Minutes, 28 July 1913; X308/1/4/1/1/2, Brown's Works Committee Minutes, 25 August 1913.
[70] X308/1/4/1/1/2, Brown's Works Committee Minutes, 30 March 1914.

the general trades of the Company.'[71] Despite their extensions, Brown saw an expansion of both their commercial and armour trade as central to their future business, much like Cammell explored above. The expansion of the company's commercial business was emphasised at their 1914 AGM, no doubt to maintain their public profile as a steel rather than an armament company, when chairman Baron Aberconway remarked to shareholders that 'The Company…were infinitely more interested in the development of peaceful trades than in warlike trades.'[72] Overall, by the outbreak of War in August 1914, Brown were struggling to maintain their relative position in the British armour business.

Brown and Cammell provide further evidence for a hierarchy of special relationships with the Government. While Vickers and Armstrong were able to secure large orders for armour and armaments, based on their duopolistic arrangements and favourable position with the Government, by 1914 Brown and Cammell were progressively exploring and expanding their commercial output as they could no longer solely rely on the limited number of armour orders for profitability. In comparison to the two companies, the proportion of annual profits provided from armaments at Vickers' River Don Works in Sheffield between 1909 and 1914 varied between 89 to 98 per cent.[73] Essentially, these two companies were viewed by the Admiralty as second-tier suppliers in comparison to their larger competitors. Away from armour production, there is also evidence of a hierarchy of supply for projectiles, as the exploration of the business of Hadfields and Firth below will demonstrate.

The Business of Armaments: The Projectile Manufacturers

In contrast to armour, projectiles involved a much larger investment in technological research and development, and a different type of procurement strategy from the Government. Projectiles were an expendable product, with new stocks required for every new ship construction and each new calibre of gun introduced. Between 1900 and 1914 this increased from 12 inch calibre to 13.5 inch and ultimately 15 inch, requiring the armament companies to update their equipment and capabilities to construct the new sizes of guns and

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[71] X308/1/4/1/1/2, Brown's Works Committee Minutes, 30 March 1914, 27 April 1914. The new plant took over the North Forge and Axel departments at the Atlas Works.
[72] *The Times*, 1 July 1914, p.20.
[73] Trebilcock, *Vickers Brothers*, pp.20-21.

projectiles.[74] Technological advances could also lead to technological obsolescence with older projectile designs, and stocks could be diminished due to testing and firing practice.

To assess Hadfields' investment in projectile technology, an examination of the commercial performance of the company and their strategies for obtaining orders is required. Table 3.14 shows the ordnance turnover (an aggregate of both shell and projectile manufacture) for Hadfields between 1897 and 1913, along with the company's profits and ordinary dividends paid to shareholders.

Table 3.14: Hadfields' Turnover, Profits and Dividends 1897-1913

	Ordnance, £,000s (Percentage)	Commercial, £,000s (Percentage)	Profit (£)	Ordinary dividend (%)
1897	63 (31)	139 (69)	19,377	7
1898	119 (42)	166 (58)	18,080	8
1899	95 (29)	231 (71)	17,368	9
1900	148 (36)	267 (64)	39,500	20
1901	427 (60)	281 (40)	82,818	25
1902	369 (50)	364 (50)	86,121	25
1903	236 (33)	482 (67)	84,051	35
1904	143 (21)	528 (79)	76,866	30
1905	178 (23)	580 (77)	86,733	30
1906	251 (24)	790 (76)	101,497	35
1907	77 (8)	853 (92)	66,170	17.5
1908	146 (16)	754 (84)	72,554	17.5
1909	67 (8)	735 (92)	68,234	17.5
1910	116 (13)	761 (87)	69,955	17.5
1911	163 (16)	842 (84)	79,477	17.5
1912	335 (27)	885 (73)	116,297	20
1913	373 (26)	1,081 (74)	109,512	20

Sources: SA, Hadfields Volume 7, OGM and EGM Minutes 1889-1919, Hadfields Box 145, Statement of Output 1888-1929.

While in the late 1890s the proportion of armaments turnover at Hadfields had averaged a third of all production, it had not yet provided an

[74] Pollard and Robertson, *British Shipbuilding Industry*, p.204.

increase in profits or rate of dividend. From 1900 onwards, following the vast increase in armaments orders to the private sector during the Boer War, the decade of investment Hadfield had put into armaments development began to pay dividends. It was at this point that the company's investment in armaments production began to have a positive impact on profits and dividend payments. For the following six years dividend payments reached their pre-Great War peak. However, Hadfield was keen to avoid the image of profiteering from armaments orders with the British Government. William Francis Kett, a Hadfields' employee from 1903 to 1905 remarked in his autobiography that:

> '…whenever the Company declared a substantial dividend, it was customary to indicate to the government officials that the general steel business was responsible for the earnings, while the engineering customers were given to understand that the profits came mostly from government orders.'[75]

From Table 3.14 we can see that the latter is the case; between 1900 and 1913, when the proportion of ordnance turnover fell below 20 percent of Hadfield's total output, dividends paid to ordinary shareholders were at their lowest level during the period. Clearly, there was a relationship between Hadfields' rate of profit and the scale of their armaments output.

From 1911 to 1914, figures for the value and tonnage of Hadfields' commercial and armaments production are available, and it is from these figures the importance of armaments production to the company can be evaluated. For this period, as presented in Table 3.15, the average value per ton of commercial work output was around £25, whereas the average value per ton of armaments work was around £80, and increased during 1914. This difference in value per ton of output is a clear indication of the lucrative returns the company could make from armaments production. However, these figures only illustrate half of the story. By exploring Table 3.16, which shows the proportion of armaments work to the overall annual output of Hadfields by ton and value, a more accurate picture emerges. While the overall proportion of Hadfields' annual output of armaments accounts for less than one-fifth of the total, the value of this output accounts for a significantly higher proportion of the company's financial returns. Therefore, while Hadfields' production of war

[75] SA, Hadfields Box 53, Extract from the Autobiography of William Francis Kett, written in the 1950s.

materials may be seen as only a small proportion of their annual tonnage output, the value of such products made armaments production a very important aspect of their commercial success.

Table 3.15: Hadfields' Work Invoiced and Average Value Per Ton Of Output

	Armaments Work		Commercial Work		Value Per Ton	
Year	**Tons**	**Value**	**Tons**	**Value**	**War**	**Comm.**
1911	2,335	£192,100	31,109	£812,600	£82.27	£26.12
1912	4,867	£375,100	35,191	£844,600	£77.07	£24.00
1913	4,918	£414,100	40,120	£1,040,500	£84.20	£25.93
1914	7,379	£641,500	33,277	£886,700	£86.94	£26.65

Source: Calculated from Hadfields Box 57, Hadfields Invoiced Output 1911-1916

Table 3.16: Hadfields' Armaments Work As A Proportion Of Total Output

	Armaments Work		Total Output		Armaments Work as a Proportion of Total	
Year	**Tons**	**Value**	**Tons**	**Value**	**Tons**	**Value**
1911	2,335	£192,100	33,444	£1,004,700	7.0%	19.1%
1912	4,867	£375,100	40,058	£1,219,700	12.1%	30.8%
1913	4,918	£414,100	45,038	£1,454,600	10.9%	28.5%
1914	7,379	£641,500	40,656	£1,528,200	18.1%	42.0%

Source: Calculated from Hadfields Box 57, Hadfields Invoiced Output 1911-1916

Hadfields' orders for projectiles expanded rapidly in 1900 due to the unprecedented level of demand during the Boer War. Between February and June 1900 the Navy ordered over 200,000 projectiles consisting of 12 different types and calibres, with 120,000 of those ordered on 7 June alone.[76] During the same period, the Army had also ordered in excess of 30,000 shells. *The Engineer* reported on 6 July that 'A number of very heavy orders for projectiles and shells generally have recently been placed in Sheffield, the business in that description of war material being unprecedentedly large.'[77] By the end of the year the Government had ordered almost 278,000 shells from Hadfields. However, the level of demand far exceeded the productive capacity of the Hecla works and Hadfields' suffered the same productive bottlenecks encountered by

[76] SA, Hadfields Volume 151, Hadfields Projectile Orders No.1, pp.3-28.
[77] *The Engineer*, 6 July 1900, p.21.

other armaments manufacturers.[78] One order placed on 10 February 1900 for 10,000 15 pound shrapnel shell, for example, which the Army had requested 2,000 per week from mid-March, did not start deliveries until November and took a further 12 months to complete.[79] Demand continued to the end of the conflict, with Hadfields' investing £40,000 of capital into new projectile plant between 1900 and 1902, including £2,100 at the East Hecla works.[80] Army orders had declined by 1903, with Hadfields' orders from the Navy providing the majority of output.

Following the introduction of the Heclon AP projectile by the Navy in 1904, negotiations had begun in early 1905 between Hadfield and Hugh Oakeley Arnold-Forster, then Secretary State for War, for a formalised agreement guaranteeing a set proportion of orders to Hadfields every year. Arnold-Forster had encouraged Hadfields to install new plant for the production of 18-pound shrapnel shell for use with new field guns introduced after the Boer War. Hadfields obliged, and in January 1905 work began on a new shrapnel shell shop at the East Hecla works, which was completed in April after 10 weeks construction, with a capacity of 400,000 to 500,000 shells per annum.[81] When the new plant became operational in May 1905, two orders had been received for 18-pound shell in January and March totalling 97,000 shells.[82] The orders were completed in 13 months, and delivered in June 1906. Negotiations with Arnold-Forster were finalised in May 1905, with the resulting agreement promising Hadfields the opportunity to tender for all projectiles ordered by the British Government for both the Army and Navy, and that 50 percent of the aggregate value of annual orders to the Trade would be placed with Hadfields for the four years from November 1904.[83] Orders received under the agreement in 1905 were more than double what had been placed by the Government the previous year, although the improvement in orders was short-lived. The resignation of the Balfour government in December 1905 removed Arnold-Forster from his position in the War Office, being replaced by Richard Haldane. The change in Government reflected a change in procurement strategy from the War Office, and in the wake of the Haldane Army Reforms orders to the Trade

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[78] See Trebilcock, War and the Failure of Industrial Mobilisation'.
[79] SA, Hadfields Volume 151, Hadfields Projectile Orders No.1, p.2.
[80] SA, Hadfields Box 56, Capital Expenditure 1897-1915.
[81] SA, Hadfields Box 103, Shrapnel Plant Notes, 29 April 1915, p.2.
[82] SA, Hadfields Box 103, Shrapnel Plant Dates File, 24 March 1915.
[83] SA, Hadfields Box 103, Shell Agreement November 1904 to November 1908.

rapidly declined in 1906.[84] A letter sent by Hadfield to the War Office in December 1906 reflected the depressed state of the trade. He reported that the number of workmen employed in Hadfields' shell department had fallen from around 1,000 under normal conditions to 230, and work in hand totalled just £19,000. One year before, Hadfields' had £180,000 of projectile orders on their books. Drawing attention to their idle shrapnel plant, and the rumour no new AP projectile orders would be forthcoming, Hadfield urged the War Office to assist them in the retention of their skilled workforce and stores of raw materials required.[85] In concluding his letter Hadfield proclaimed:

> Our works may truly be described as having been your shell Arsenal in the North of England, as outside Field Artillery Shrapnel shell, we believe we have made not far short of about 75% of your total requirements in common, semi-armour piercing, practice, capped and uncapped shot and shell.[86]

This is an interesting insight into the value which Hadfield placed on his works contribution to the British military, viewing it as equally important as those maintained by the Government. When a response came in January 1907, Hadfield were informed that only orders for 18-pound shrapnel shell would be forthcoming.[87] He readily accepted, while again emphasising the need to not let AP shell manufacture cease.[88] Two orders for 18-pound shrapnel shell from the War Office, totalling 37,500 units were placed in February and June 1907, along with a solitary order for 800 12 inch Heclon AP shells in April worth £25,000. Hadfield's efforts to gain orders had not gone unheeded, but it would be the last time the shrapnel plant would be in operation. Haldane visited the East Hecla works in November 1907, at which time the 18-pound shell orders had been completed. Haldane was informed that Hadfields were in desperate need of more orders but none were placed. [89] Further letters requesting orders were sent to the War Office but all were unavailing.[90] The shrapnel shell plant was kept in working order until May 1909, at which time the plant was permanently

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[84] See Table 3.1 to 3.3 above.
[85] SA, Hadfields Box 103, Robert Abbott Hadfield to War Office, 14 December 1906.
[86] SA, Hadfields Box 103, Robert Abbott Hadfield to War Office, 14 December 1906.
[87] SA, Hadfields Box 103, War Office to Robert Abbott Hadfield, 11 January 1907.
[88] SA, Hadfields Box 103, Robert Abbott Hadfield to War Office, 21 January 1907.
[89] SA, Hadfields Box 103, Remarks Regarding The Shell Plant Of Hadfields Sheffield, July 1915.
[90] SA, Hadfields Box 103, Shrapnel Proof Letter, 7 June 1915, p.2.

closed and dismantled through to September 1911.[91] The issue of Hadfields' shrapnel plant would resurface in 1915 during the height of the Shell Crisis. While Hadfield may have believed he could exert an influence over the supply ministries, in reality the Admiralty and War Office held the most powerful position in their relationship with private industry.

The record of Hadfields reflects the instability of demand when dealing with a monopsonist buyer, which was influenced by changes in the international environment, requirements needs in national crises, and changes in procurement strategies by successive Governments. While being offered 50 percent of the value of all orders, in times of low demand this could result in few orders being placed. The decline in demand from late 1906 until 1907 was reflected in Hadfields' performance (See Table 3.14), the company reporting at its 1908 OGM that 'There has…been an exceptional falling off in the orders received from the British Government for War material.'[92] At the same meeting, Hadfield vented his frustrations at the preferential treatment that had been granted to the British ordnance factories during these slack years. Quoting figures which showed that the Royal Arsenal had gained 26 percent of work in 1900-3, and 42 percent in 1904-6, Hadfield stated that he 'thought the Arsenal ought to suffer proportionately' in time of lean demand.[93] At the 1909 OGM, Hadfield's anger with the Government did not abate, and he accused them of introducing an 'irreducible minimum' at Woolwich, which guaranteed a set amount of work each year to the Ordnance Factories. If the Government was to give preferential treatment to its own arsenal, Hadfield concluded, then it was only fair that this should be extended to the private sector. After all, 'Sheffield had done far more for the Empire than Woolwich ever had, or could do. He did not see why one part of the country should be benefitted at the expense of another part of the country.'[94] Hadfields' 'Arsenal in the North of England' was clearly not as highly valued as Hadfield had hoped in Whitehall.

By examining Hadfields' invoiced output to both the Army and Navy in Table 3.17, it can be seen that orders for the Admiralty were predominant at Hadfields, backed by the introduction of three key products; Heclon AP projectiles, Eron CPC projectiles, and ERA cast steel armour. Conversely, Army

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[91] SA, Hadfields Box 103, Shrapnel Dates File, 24 March 1915.
[92] SA, Hadfields Volume 7, OGM and EGM Minutes 1889-1919, 19 March 1908, pp.75-76.
[93] *Sheffield Daily Independent,* 20 March 1908.
[94] *Sheffield Daily Independent,* 23 March 1909.

orders can be examined in three phases. From 1900 through to 1903, Army demand was inflated due to the Boer War, in 1903 accounting for almost two-fifths of Hadfields British Government output. Following the end of the conflict, Army orders rapidly declined, before being bolstered by initially large shrapnel shell orders under the 1904-1908 British Government agreement, before becoming virtually non-existent prior to the Great War.

Table 3.17: Hadfields' Invoiced Output For British Army and Navy 1900-1914

Year	Army, £,000s (Percentage)	Navy Including ERA Steel, £,000s (Percentage)	Total British Government, £,000s
1900	11 (8)	131 (92)	142
1901	106 (25)	321 (75)	427
1902	94 (27)	258 (73)	352
1903	93 (39)	143.5 (61)	236.5
1904	7.5 (6)	120 (94)	127.5
1905	38 (21)	140 (79)	178
1906	69 (27)	186 (73)	255
1907	17 (18)	75 (82)	92
1908	12 (8)	144 (92)	156
1909	0.6 (1)	75 (99)	75.6
1910	0 (0)	79 (100)	79
1911	1 (1)	153 (99)	154
1912	3 (1)	250 (99)	253
1913	0 (0)	274 (100)	274
1914	27 (5)	509 (95)	536

Source: Hadfields Box 113, Hadfields Invoiced Outputs 1899-1915.

In 1905, after their agreement with Arnold-Forster Hadfields began to expand their productive capacity to serve the whole of the British military in peacetime. The company invested capital in establishing a shrapnel plant which could initially supply up to 500,000 projectiles annually, with the possibility to expand to 1 million rounds a year. However, a change in government and a new procurement strategy under Haldane curtailed this expansion and moved Hadfields away from being a producer for the British Government, and back to one principally concerned with supplying the Navy. In this regard, Hadfields were the only one of the four Sheffield armaments companies which managed to foster, albeit temporarily, a closer working arrangement with the Army.

Following the end of Hadfield's original four year agreement with the Government, a revised arrangement was signed exclusively with the Navy for the two years from November 1908 to November 1910. Once again the contract agreed that Hadfields would receive half of all the projectile orders placed with the Trade for the duration of the agreement.[95] This change in contract reflected a forthcoming change in procurement arrangements at Whitehall, as from 1909 the Admiralty would take control of the allocation of Naval contracts from the War Office.[96] Two Navy orders totalling 800 12 inch Heclon AP shells were received in December 1908 worth £20,000, although it would be almost a year before further orders were received for either the Heclon or Eron. When the agreement was renewed a third time in January 1911, the Admiralty opted to reduce Hadfields' guaranteed share of orders from one half to two fifths of all orders placed with the Trade.[97] While the prices agreed for projectiles (See Table 3.18) reflected the high price of the technological research and development behind the Heclon and Eron calibres compared with common shell types, the reduction in Hadfield's proportion of orders was clearly a catalyst for Hadfield to sign a similar agreement with the Imperial Japanese Navy just two months later, examined in the following chapter. Hadfields' original 50 percent proportion of orders was restored in January 1913 when the company's fourth agreement was signed with the Admiralty. By this point, the revised three year agreement covered only Heclon AP and Eron CPC projectiles. The company had finally secured a guaranteed proportion of only the highest priced projectiles they manufactured.

The series of agreements from 1905 to the Great War demonstrate the nature of the special relationship Hadfields had with the Government. By securing at least half of all the projectile orders to the trade each year, the company was the most highly regarded projectile manufacturer in the country and was certainly in the 'first tier' of armaments suppliers. However, this did not make them immune from armaments supply changes in Whitehall, again

[95] SA, Hadfields Box 103, Shell Agreement November 1908 to November 1910.
[96] Lloyd-Jones and Lewis, Armaments Firms, p.32.
[97] SA, Hadfields Box 103, Hadfields Shell Agreement 1911-1913.

demonstrating a power relationship which favoured the Government. Hadfields obliged in constructing new capacity for Army requirements in 1905 and were initially rewarded for their investment. With a change in Government, Hadfields' compliance was no longer as highly regarded and their new capacity was rendered surplus to requirements. Nevertheless, by securing a set proportion of all orders to the trade for naval requirements the technological investment made by Hadfields in projectiles was regarded by the Government. As the case of Firth will demonstrate, not all the projectile manufacturers in the industry could command such a relationship.

Table 3.18: Hadfields-British Admiralty Shell Prices 1911

Type of projectile	Price per 100 (£)
15 inch Heclon armour piercing with cap	6400 (1913 price)
15 inch Eron common pointed with cap	6525 (1913 price)
13.5 inch Heclon armour piercing with cap (1,400 lbs)	4345
13.5 inch Eron common pointed with cap (1,400 lbs)	4525
13.5 inch Heclon armour piercing with cap (1,250 lbs)	4350
13.5 inch Eron common pointed with cap (1,250 lbs)	4350
13.5 inch lyddite (1,400 lbs)	2750
13.5 inch lyddite (1,250 lbs)	2575
12 inch Heclon armour piercing with cap	2555
12 inch Eron common pointed with cap	2475
12 inch lyddite	1560
10 inch lyddite	1092
7.5 inch lyddite	355
6 inch Eron common pointed with cap	483
6 inch lyddite	220
4 inch lyddite	86
4 inch common pointed shell	73.5
12 and 14 pounder lyddite	52.5

Source: SA Hadfields Box 103, Hadfields Shell Agreement 1911-1913, Volume 152, Hadfields projectile orders No.2, p.104, 28 May 1913, and p.114, 26 July 1913.

As discussed in Chapter 1, Firth invested in projectile technology in a comparable manner to Hadfields and were able to licence their Hollow Cap design across the world. By examining the financial record of the company and their strategies for obtaining projectile orders the value of Firth's technological investment can be explored. An overview of their financial performance between 1899 and 1913 is provided in Table 3.19.

Table 3.19: Firth's Sales, Profit and Dividends 1899-1913

	Commercial To 1909, Total Sales From 1910 (£,000) (Percentage)	Gun Works (£,000s) (Percentage)	Profit (£)	Ordinary Dividend (%)
1899	252 (52)	236 (48)	£110,850	20½
1900	287 (49)	300 (51)	£144,017	25
1901	270 (43)	365 (57)	£136,326	22½
1902	250 (60)	166 (40)	£50,454	10
1903	245 (52)	225 (48)	£62,348	10
1904	265 (65)	141 (35)	£56,884	7½
1905	315 (65)	169 (35)	£82,853	10
1906	347 (58)	248 (42)	£85,971	10
1907	328 (67)	161 (33)	£51,702	7½
1908	319 (63)	189 (37)	£58,203	5
1909	311 (58)	223 (42)	£69,265	5
1910	598 (100)	No data	£62,609	5
1911	709 (100)	No data	£99,693	7 ½
1912	837 (100)	No data	£123,349	12 ½
1913	1,068 (100)	No data	£159,004	12 ½

Sources: SA, X306/1/2/2/1/1, Firth's General Meeting Minute Book No.1, X306/1/3/2/2, Secretary's Reports No.3., X306/1/2/3/2, Firth's Directors Meeting Agendas and Papers 1903-1914.

The large influx of orders during the Boer War helped boost the Gun Works sales to half of the output of Firth during 1899 to 1901, but this increase in orders was short-lived. In December 1901, Bernard Firth reported that orders for the British Government were 'exceedingly light', and at the start of 1902, the Gun Works were short of shell work and forgings.[98] Firth failed to secure any projectile orders in 1901, demonstrating the inconsistent demand from the

98 SA, X306/1/2/3/1/2, Firth's Directors Meeting Minutes, 13 December 1901; X306/1/2/2/1/1, Firth's General Meeting Minutes, 18 April 1902.

British Government for armaments. The once busy Gun Works could be rapidly rendered idle when orders for projectiles failed to materialise. This is reflected in the declining dividends from 1902 when sales at the Gun Works fell below half of the Norfolk Works output. However, after 1903 it is less reliable to use dividend payments to gain a perspective on the year on year prosperity of Firth. As 7/8ths of Firth's ordinary stock was held by Brown thereafter, the majority of dividend payments would be direct to their parent company. In 1911 it was also stated that 'It was considered policy not to pay more than a 5 percent dividend and to meet alterations and improvements out of Revenue and not to allow the Capital to rise to unwieldy dimensions.'[99] This policy was applauded by Firth's directors and shareholders in 1912 for the increase in the previous year's profit.

Table 3.20: Firth's British Government Projectile Orders 1900-August 1914

Year	British Army (£,000) (Percentage)	British Navy (£,000) (Percentage)	Total British Government (£,000)
1900	37 (20)	147 (80)	184
1901	*None*	*None*	*None*
1902	125 (100)	0 (0)	125
1903	4 (20)	16 (80)	20
1904	9 (13)	61 (87)	70
1905	10 (9)	97 (91)	107
1906	*None*	*None*	*None*
1907	*None*	*None*	*None*
1908	0	10 (100)	10
1909	0	34 (100)	34
1910	0	97 (100)	97
1911	0	102 (100)	102
1912	3 (5)	61 (95)	64
1913	3 (3)	107 (97)	110
1914 (To August)	0	230 (100)	230

Sources: Calculated from TNA, WO 395/1 and 2, Director of Army Contracts Reports 1900-14, Firth's Directors Records, Firth's Reports to Brown's Board, 1906-1913.

[99] SA, X306/1/2/2/1/1, Firth's General Meeting Minutes, 25 April 1911.

However, when profits and output fell Firth were quick to blame a falling away of Government orders at their AGM in 1907, unsurprising as Firth received no projectile orders since 1905.[100] Turnover from Government work was £2,000 lower per week in 1907 than the previous year, as shown in Table 3.20.[101] Poor results at the Gun Works in 1910 were once again blamed on a lack of projectile orders.[102] This indicates that, much like other Sheffield armourers, Firth were predominantly tied to their Gun Works and continued technological development of projectiles for their profitability. An attempt to move away from this reliance was made with the completion of a new works at Tinsley in 1908, and the expansion of the foundry and Siemens departments at the Norfolk Works. These developments promoted the growth of Firth's commercial output and helped decrease the company's reliance on armaments orders for profitability.

However, Firth did not overlook investment in the Gun Works as part of their expansion plans. In addition to maintaining their technological position, Firth were also determined to expand their production capabilities in line with British Government requirements. Before the Great War, 13.5 and 15 inch guns were introduced on Navy ships, necessitating projectiles of the same calibre to be manufactured for their operation.[103] In order to ensure the company could tender for and supply 13.5 inch projectiles the machining capacity at the Gun Works was expanded in 1910 beyond their previous limit of supplying 12 inch projectiles.[104] The capacity was again expanded in April of 1913 to enable the production of up to 80 16.5 inch calibre projectiles per week.[105] Even in times of low demand, Firth needed to keep the company in a position to supply the British Government. The increasing size of projectiles was also reflected in their increasing price. If a lucrative order was forthcoming from the Government the company had to be prepared for their manufacture or risk loosing potentially large profits.

By examining the orders received by Firth for projectiles from the British Government in Table 3.20, it is apparent that the company was predominantly a Navy supplier, outside of a small period of increased Army orders during the

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[100] SA, X306/1/2/2/1/1, Firth's General Meeting Minutes, 16 April 1908.
[101] SA, X306/1/2/2/1/1, Firth's General Meeting Minutes, 16 April 1908.
[102] SA, X306/1/2/2/1/1, Firth's General Meeting Minutes, 25 April 1911.
[103] Pollard and Robertson, *British Shipbuilding Industry*, p.204.
[104] SA, X306/1/2/3/2/90, Firth's Directors Meeting Papers, 1 March 1910.
[105] SA, X306/1/2/3/2/130, Firth's Directors Meeting Papers, 29 April 1913.

Boer War.[106] The Army orders received in 1902, which boosted the fortunes of the Gun Works temporarily, were all received on 14 June. It was Firth's first shell order in 18 months, and it would be another 10 months before any more were received. After this brief increase, Army requirements disappeared, leaving Firth reliant on the Navy for orders from the British Government, whose demands could rapidly fluctuate or disappear as they had in 1906-7. A predominant issue for Firth was that, unlike Hadfields, they were outside of any formal arrangement for supply to the Government. The company did explore the possibility of ensuring some stability for their projectile output, though they were unsuccessful in attempting to arrange a schedule of prices with the Admiralty in 1911.[107] Considering that from 1905 though to the Great War, Hadfields gained around a half share of all Navy orders, this left Firth fighting for a proportion of the remaining half with other manufacturers. By 1914 the list included Armstrong and Cammell, both of whom licensed Firth's Hollow Cap designs, for armour piercing projectiles, Vickers and the Projectile Co for smaller calibre common shell, and Harper Bean for practice shot.[108] Cammell had introduced the manufacture of projectiles in 1898 as an adjunct to their armour business. Orders had increased due to Army demands during the Boer War, but the company too suffered a dearth of orders in 1901, 1906 and 1907 the same as Firth, as shown in Table 3.21. Orders increased through to 1914 with a growing number from the Admiralty, which in part rescued the fortunes of the department which had been running at a loss for some years, as shown in Table 3.22.

At Firth, the problems stemming from being outside of favourable arrangements with the Government were evident in February 1912 when the company received orders for 400 13.5 inch AP and 400 13.5 inch CPC projectiles, worth £39,000. After recent successful trials with their projectiles, Firth's board of directors had expected more, and communicated to the Admiralty their disappointment at the small size of the order.[109] The same month, Hadfields received orders for 2,400 13.5 inch Heclon AP and Eron CPC projectiles, worth £107,000. Hadfields had, through their relationship with the Admiralty, secured three quarters of the orders available. The Government

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[106] See Trebilcock, War and the Failure of Industrial Mobilization.
[107] SA, X306/1/2/3/1/4, Firth's Directors Meeting Minutes, 25 July 1911, 29 August 1911.
[108] TNA, WO 395/3, Director of Navy Contracts Report 1914, pp.132-3.
[109] SA, X306/1/2/3/1/4, Firth's Directors Meeting Minutes, 27 February 1912.

clearly had a preferred partner for projectiles in their network of 'special relationships,' compounded by Hadfields' arrangements with the Admiralty regarding their minimum share of orders. Firth were suppressed into the second tier of 'special relationship' suppliers, and would have to find alternative means of maintaining production at the Gun Works, and retaining the specialist staff involved in projectile manufacture. The use of international markets as a defence against this type of uncertainty is explored in the next chapter.

Table 3.21: Cammell's Shell Orders From British Government, 1900-1914

Year	British Army Shell Orders, £,000s (Percentage)	British Navy Shell Orders, £,000s (Percentage)	Total British Government Orders, £,000s
1900	153 (83)	31 (17)	184
1901	*None*	*None*	*None*
1902	18 (50)	18 (50)	36
1903	4 (100)	*None*	4
1904	2 (13)	13 (87)	15
1905	54 (92)	5 (8)	59
1906	*None*	*None*	*None*
1907	*None*	*None*	*None*
1908	*None*	No data	Unknown
1909	*None*	No data	Unknown
1910	0.9	No data	Unknown
1911	18 (58)	13 (42)	31
1912	8 (9)	85 (81)	93
1913	0.7 (2)	28 (98)	28.7
1914 (To July)	0.7 (1)	85 (99)	85.7

Source: Calculated from TNA, WO 395/1 and 2, Director of Army Contracts Reports 1900-14

Table 3.22: Cammell's Shell Plant Profits and Losses 1910-1914

Year	Profit (Loss) (£)
1910	(14,747)
1911	(6,111)
1912	(3,822)
1913	2,118
1914	5,831

Source: SA, ESC Box 192, Cammell Laird Sheffield Outputs 1910-1927

One way to combat Firth's singular dependence on the Government was to collaborate with other companies which supplied projectiles. This was the case with the London based Projectile Co, which also had Bernard Firth as its chairman. A broad technology sharing and supply arrangement was entered into between the two in 1905, without the signing of a formal agreement. Part of the understanding was for Firth to supply cast steel blocks for some of the Projectile Co's requirements.[110] Firth would also promote the Projectile Co alongside their own works in advertising materials.[111] There was also some joint tendering for projectiles between the companies, with the two securing £130,000 of orders for 13.5 and 15 inch AP projectiles in January 1914. However, due to a lack of communication and co-ordination between the two, the order was wholly taken up by Firth as the Projectile Co could not machine the size of projectiles required. While this appeared to be a suitable arrangement in principle, the debacle resulted in Firth rearranging most of the Gun Works and spending £5,000 on new machinery in order to manufacture the required 60 13.5 inch shell per week.[112] This was certainly not the most ideal arrangement for Firth, and highlights the issues of inter-company collaboration without any explicit means of managing and co-ordinating the arrangements entered into. As chairman of both companies, Bernard Firth was the only formal means of communication between Firth and the Projectile Co, though his activities as a facilitator of collaborative productive efforts were inefficient and ineffective. As will be explored in the following chapter with the Coventry Ordnance Works, a greater overlap of directors and armaments experts in conjunction with formal arrangements for supply helped to mitigate this level of inter-firm uncertainty.

Despite being outside of any supply agreements with the British Government, Firth strived to maintain their position as a key supplier of projectiles. In order to remain competitive for tendering with an expanding range of calibres in use, the company was forced to increase their capabilities to manufacture the larger projectiles with no guarantee of orders. Firth were firmly in the second tier of 'special relationships' with the Government, and in 1901,

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[110] SA, X306/1/2/3/1/3, Firth's Directors Meeting Minutes, 28 August 1905, 25 September 1905, 31 October 1905, 28 November 1905.
[111] For an example of Firth's promoting Projectile Co, see SCL, *Modern Projectile Factories of Thomas Firths & Sons Ltd*, 1912, p.6.
[112] SA, X306/1/2/3/2/140, Firth's Directors Meeting Papers, 24 February 1914.

1906 and 1907 failed to secure any projectile orders from their home buyer. Their collaborative relationship with the Projectile Co had the potential to counter the general uncertainty of orders from the Government, but it lacked the required managerial coordination to ensure any successes. Nevertheless, at home Hadfields were certainly the preferred supplier for their monopsonist buyer, leaving Firth to fight for a portion of the remaining tenders available each year.

Conclusion

Overall, the Sheffield armaments industry was part of a naval-industrial complex, supplying the Admiralty with armour and projectiles in an environment characterised by uncertainty. The relationships between the government and private industry can be explored through the notion of 'special relationships' as outlined by Trebilcock, a relationship in which strong home demand allowed the armourers to finance their own research and development activities and market their products to their home governmental buyers. However, by going beyond this definition it is possible to demonstrate a hierarchy of relationships involved, with more favoured suppliers in the first rank, the remaining companies in the second rank. Those in the first rank included Vickers and Armstrong for armour and Hadfields for projectiles, though this is not to suggest that Hadfields were viewed in the same high esteem as their larger counterparts. The second rank of companies comprised the remaining members of the Sheffield armaments industry, Brown, Cammell and Firth. The companies in the first rank were involved in favourable relationship with the government, either through attempts to stifle rivals in armour and gun manufacture or with guaranteed supply arrangements as Hadfields secured. The companies in the second rank had to fight for a share of the remaining orders. Relationships with the supply ministries were also facilitated by the addition of ex-military personnel to the boards of directors of all the armaments companies, the use of London offices and in the case of Robert Abbott Hadfield, his home close to Whitehall. The relationships between companies and the supply ministries also demonstrate one aspect of armaments marketing. A key part of the special relationships involved the compliance of the companies involved, the case of Cammell demonstrating the consequences of falling from favour of the Government. Away from supplying the Government with their main armaments products, the

Sheffield armaments companies all implemented multi-faceted corporate strategies which incorporated a number of defensive measures to counter uncertainty in the industry. The use of director networks, collaborative production, and international business are all explored in the following chapter.

Chapter 4: Defence against Uncertainty – Director Networks, Collaboration and International Business 1900-1914

In the decade before the Great War British armaments companies were technological leaders and innovators in the industry despite the fact that they faced a home market characterised by uncertainty. Although favourable special relationships with the government were available to a select few, including Vickers, Armstrong and to some extent Hadfields, and less favourable relationships for Brown, Cammell and Firth, there were no guarantees of orders to private industry. In response, each company implemented their own multi-faceted corporate strategy, which included a number of defensive measures in an attempt to counter the insecurity of their home market. The degree to which each company sought defensive measures was related to how favourable they were in the eyes of the British Government, but in all cases each hoped to capture more orders, make further returns on their investment in research and development, and maintain their trained staff and productive facilities in operation.

The means by which the armaments companies defended against the uncertainty in their home market can be divided into three areas, which provide the structure for this chapter. Firstly, companies may act collaboratively in order to place them in a more favourable position with their home buyer. In this regard, the actions of Brown, Cammell and Firth require further examination. Through share exchanges, mergers and acquisitions, by 1905 the three companies had constructed a network of productive facilities, and an important network of directors centred on the Coventry Ordnance Works (COW), a company established to manufacture guns and gun mountings to counter the duopoly of Vickers and Armstrong. The director network constructed also allowed the group of companies to share risk and knowledge. Secondly, in order to capture foreign markets companies may again act collaboratively to increase their chance of success. Here, the actions of Brown come to the fore. Uniquely, the company was part of two combines attempting to enter foreign markets for armaments. One group was linked to their involvement with COW, the other a combined effort with Vickers and Armstrong to gain orders in Spain and Turkey, a grouping in which Brown found themselves the junior member and a cause of tension regarding the foreign prospects for the products of the

COW. The level of collaboration in the British armaments industry was somewhat unique compared to their European rivals. Research into German and Italian armaments production prior to the Great War, for example found a weak association between companies in both countries.[1] Essentially, the British armaments industry utilised a mix of competition and cooperation, especially in the international market. Companies may often complement each other in making markets, but are competitors when dividing them up.[2] Thirdly companies attempted to enter international markets individually in a bid to secure orders from a foreign government without having to share them. International orders were certainly valuable to armaments companies, who can be seen as 'pioneer multinationals'[3] Overall these efforts were an essential part of being an armaments company, the highly specialised nature of their work promoting the need to actively seek new ways to profit from their heavy investment in research and development and production facilities.

Director Networks and the Coventry Ordnance Works

In order to explore the relationships between Brown, Cammell and Firth, a brief overview of the evolution of the group and the facilities they controlled is required (See Figure 4.1). In 1899, Brown took over the Clydebank Engineering and Shipbuilding works to gain an outlet for their armour production, and supplemented their shipbuilding interests by acquiring a controlling interest in the Belfast based Harland and Wolff Company in 1908.[4] The Clydebank shipyards became part of Brown, while Harland and Wolff remained independent and not involved in the armaments business. Brown also gained a majority interest in Firth in 1902 which led to an exchange of shares and directors, though the two companies retained independent identities.[5] Firth from 1896 operated the Firth Sterling Steel Company in the US, and the Salamander Works for producing shell in Riga from 1904. In 1908, the armaments side of Firth Sterling became a separate company, the Washington Steel and Ordnance Works. Each was managed by Lewis Firth, one of the original

[1] G. Marchisio, Battleships and Dividends: The Rise of Private Armaments Firms in Great Britain and Italy c.1860-1914, (Durham University, Unpublished PhD Thesis, 2012), p.231.
[2] B.J. Nalebuff and A.M. Brandenburger, *Co-opetition* (London, Harper Collins Business, 1996), p.34.
[3] K. Warren, *Armstrongs of Elswick: Growth in Engineering and Armaments to the Merger with Vickers* (London, Macmillan, 1989), p.xii.
[4] A. Grant, *Steel and Ships, The History Of John Browns* (London, Michael Joseph, 1950), p.37.
[5] Grant, *Steel and Ships*, p.38.

directors of Firth from 1881. The use of family networks was the most common approach to international business, and a cost-effective means of developing an overseas business organisation.[6] Finally, in 1903 Cammell took over the Laird Brothers shipyard in Birkenhead and acquired the Coventry based Mulliner-Wigley Co for the production of guns. Mulliner-Wigley evolved into COW, whose ownership pattern changed in 1905 with Brown acquiring half of the shares in the company. The same year Cammell obtained half the shares of the Fairfield Shipbuilding Company, and transferred a quarter of the shares in COW to the shipbuilder.[7] Overall, the group had at their disposal the facilities to construct and equip a complete battleship. These connections were part of a move in the armaments industry to create vertically-integrated 'complete' groups able to manufacture the widest range of products for the Government.[8] The focus of this discussion of COW is based upon the development of cross-directorships and the formation of a knowledge and risk sharing network, and in the following section collaborative action in the international armaments market.[9]

The development of COW began with the acquisition by Cammell of gun manufacturers Mulliner-Wrigley in 1903, which by March 1905 had secured an order for the production of complete 13 and 18 pound artillery batteries.[10] This was part of an attempt by Cammell to become a more complete armaments company through diversification into gun manufacture and shipbuilding. The aim was to achieve a position which would provide Cammell, alone or

[6] M. Casson and H. Cox, 'International Business Networks: Theory and History', *Business and Economic History*, Vol.22, No.1 (1993), pp.47-48.
[7] On Fairfields, see C. More, 'Armaments and Profits: The Case of Fairfield', *Business History,* Vol.24, No.2 (1982), pp.175-185; and K. Warren, *Steel, Ships and Men: Cammell Laird and Company 1824-1993* (Liverpool, Liverpool University Press 1998)*,* Chapter 9 on the arrangements between Cammell and Fairfields, which included Fairfield marketing Cammell's armour to foreign customers.
[8] The merger movement in British industry at this time is covered by L. Hannah, 'Mergers in British Manufacturing Industry, 1880-1918', *Oxford Economic Papers*, Vol.26, No.1 (1974), pp.1-20. On general attitudes towards combination before 1914, see J.F. Wilson, *British Business History, 1720-1994* (Manchester, Manchester University Press, 1995), pp.98-106.
[9] The story of COW, their financial difficulties, issues with securing contracts, the burdens they placed upon the three parent companies, and the Mulliner scandal, have been explored elsewhere. See Warren, *Steel, Ships and Men*, Chapter 9; R. Lloyd-Jones, and M.J. Lewis, 'Armaments Firms, The State Procurement System, and the Naval Industrial Complex in Edwardian Britain', *Essays in Economic and Business History,* Vol.29, No.1 (2011), pp.23-39; C. Trebilcock, *The Vickers Brothers: Armaments and Enterprise 1854-1914* (London, Europa Publications, 1977), pp.93-5; R. Lloyd-Jones and M.J. Lewis, *Arming the Western Front: War, Business and the State in Britain 1900*-1920 (London, Routledge, 2016), pp.65-9.
[10] The National Archives (TNA), WO 395/2, Director Of Army Contracts Report 1905, p.18. The order was collaborative with Vickers and Armstrong, who ultimately allowed Cammell to use their designs and patents. Cammell were an unwanted partner to the two established companies, who actively attempted to stifle the development of what would become COW. See Trebilcock, *Vickers Brothers*, pp.93-5.

collaboratively, the ability to fully equip a battleship with the largest guns and gun mountings. As Warren argues:

> For these later steps it was felt desirable to form a still wider association of interests, making what had already been achieved into the nucleus for a 'complete', major, armaments group, which might match the comprehensiveness and even the size of Armstrong-Whitworth and Vickers-Beardmore.[11]

This desire to break the duopoly of Vickers and Armstrong was solely based on increasing each company's market share, increase their profitability, and make their products more desirable in the uncertain environment that the companies faced. In response, Vickers and Armstrong actively campaigned to keep COW out of a market which they had 'come to see as their shared domain.'[12] Nevertheless, the establishment of COW was welcomed in the supply ministries, and Davenport-Hines has suggested that the Government used the company to check on the prices of their competitors.[13] Overall, the establishment of COW and its ownership pattern gave each of the shareholders access to external networks to extend their production capabilities, in contrast to the use of costly internal expansion.[14]

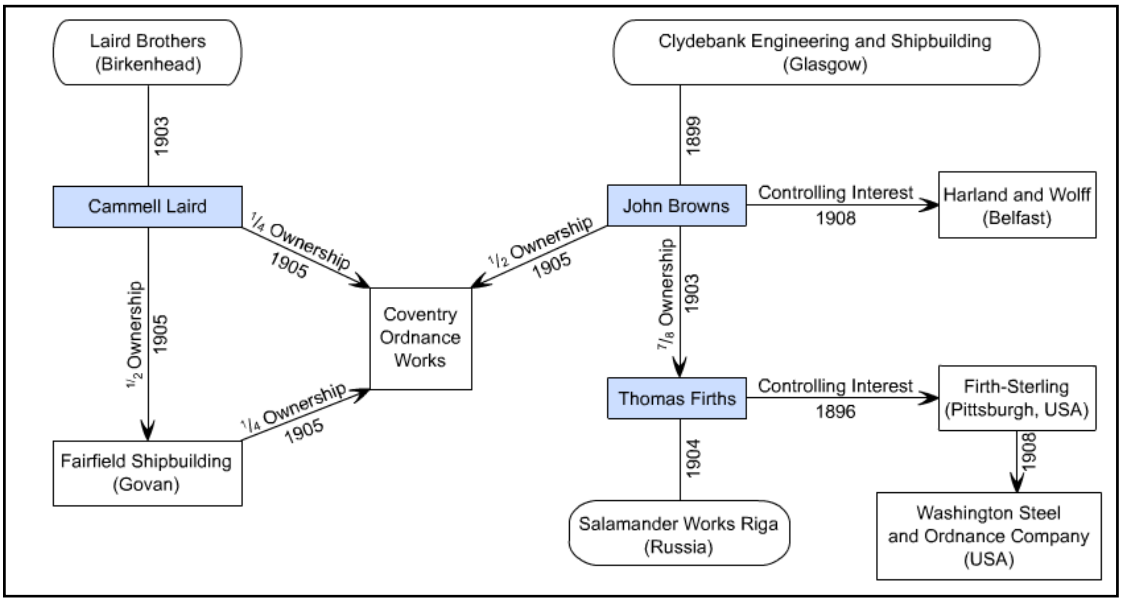

Figure 4.1: Evolution of Brown's, Cammell's and Firth's business connections 1896-1908.

[11] Warren, Steel, Ships and Men, p.141.
[12] Trebilcock, *Vickers Brothers*, p.61.
[13] R.P.T. Davenport-Hines, 'The British Marketing of Armaments 1885-1935' in R.P.T. Davenport-Hines, *Markets and Bagmen: Studies in the History of Marketing and British Industrial Performance 1830-1939* (Aldershot, Gower Publishing, 1986), p.150.
[14] See J. Brown and M. Rose, 'Introduction', in J. Brown and M. Rose, *Entrepreneurship, Networks And Modern Business* (Manchester, Manchester University Press, 1993).

A key part of the development of inter-company collaboration was the creation of a small network of directors centred on Coventry, which reflected the interests and technological capabilities of not just the three partners, but Firth as well (See Table 4.1). Cross directorships were not uncommon in the industry, for instance from 1902 William Beardmore, Albert Vickers and Trevor Dawson were on the board of Vickers and Beardmore after an exchange of shares between the two companies.[15] This network of directors served three purposes for the companies involved; it was a means of sharing and exploiting knowledge related to armaments, a means of spreading the burden of new technological risks, and finally a means of facilitating collaboratively tendering for international orders. The use of a director network for inter-firm collaboration can also be seen as an effective means of communicating explicit knowledge. Grant suggests that:

> Inter-firm collaborative arrangements are efficient mechanisms to transfer and integrate explicit knowledge and to support vertical supply relations in instances where knowledge cannot be completely embodied within the products being exchanged.[16]

Research and development was core to the business of any armaments company, and the marketing and licensing of technology a key element of the industry. Thus, the means of simplifying the exchange of technology through formal collaboration between companies was welcomed by those involved as it supported vertical supply relations.

A broader view of the whole network has been taken by Pollard and Robertson who examined the number of directors and important shareholders with connections with the government, House of Commons, civil service, and service ministries the armaments companies had. In their analysis, the Cammell-Brown-Firth-Fairfield-COW group contained 18 such individuals, while Armstrong had 10 and Vickers-Beardmore 11.[17] This was a well connected network which could access key marketing channels when required. One of Cammell's longest serving directors, Samuel Roberts MP, was recorded in 1909 as having asked six questions in just five weeks to the House of Commons to

[15] Warren, *Armstrongs,* p.106.
[16] R.M. Grant, 'A Knowledge-Based Theory of Inter-Firm Collaboration', *Academy Of Management Best Papers Proceedings* (1995), p.19.
[17] S. Pollard, and P. Robertson, *The British Shipbuilding Industry, 1870-1914* (Cambridge, Mass., Harvard University Press, 1979), p.222.

enquire 'with increasing indignation' how soon gun mounting orders would be placed with COW.[18] Furthermore, COW became the communication point for the network, where the most efficient means of sharing information and knowledge could take place.[19] This was facilitated by the number of important and well connected armaments directors serving with the company.

Table 4.1: Brown-Cammell-Firth-COW Network Cross Directorships To 1914

Name	Firth	Brown	Cammell-Laird	COW
Baron Aberconway (Charles McLaren)	A: 1903	A: 1883, DC from 1897, C from 1906		
Restel Ratsey Bevis			A: 1904, MD from 1911 to 1912 L: 1913	A: 1905 L: 1905
George J. Carter			A: 1912, MD from 1912	A: 1912
Charles E. Ellis	A: 1903	A: 1884, MD from 1892		A: 1905
Bernard A Firth	A: 1888, MD from 1900, C from 1903	A: 1903, DC from 1906		A: 1912
Alexander Gracie			A: 1905	A: 1906
Major Arthur Handley			A: 1908	A: 1908 L: 1911
William Lionel Hichens			A: 1911, C from 1911	A: 1911, C from 1913
John Macgregor Laird			A: 1904, DC from 1904, C from 1905 L: 1907	A: 1905 L: 1907
Herbet Hall Mulliner			A: 1903 L: 1905	A: 1905, MD from 1905 L: 1909
John Sampson	A: 1899	A: 1904		
Captain Tolmie John Tresidder	A: 1891			A: 1905

Key: A = appointment to board L = left board C = chairman
DC = deputy chairman MD = managing director

Note: Two included on the table – Aberconway and Sampson – were not part of the COW board. A third director, Frederick C. Fairholme, served on both the Cammell and Firth boards, but not at the same time and is not included.

Structurally, the group of companies resembles the Network-Form as outlined by Wilson and Thompson, albeit without the required investment in

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[18] P. Noel-Baker, *The Private Manufacture of Armaments* (London, Victor Gollancz, 1937), p.140.

[19] On business and organisations as communication nodes, see G. Boyce, 'A Professional Association As Network And Communicating Node: The Pharmaceutical Society Of Australasia, 1857-1918', *Australian Economic History Review*, Vol.39, No.3 (1999), pp.258-283, and G. Boyce, 'The Steel Manufacturers' Nickel Syndicate Ltd., 1901-39: Assessing the Conduct and Performance of a Cooperative Purchasing Organisation', *Australian Economic History Review*, Vol.38, No.2 (1998), pp.155-175. In this latter case Boyce identifies Vickers as the communication node for the Steel Manufacturers Nickel Syndicate, a raw material supply network for the armaments industry.

central management and co-ordination centred on COW. This type of organisational is characterised by the highly devolved nature of decision making, and 'also imposes even more managerial strains on a firm, given the need not only to run these geographically dispersed operations, but also to monitor relations with partners that might be prone to opportunistic behaviour.[20] This was the case with the COW network, as the construction of a completed capital ship could involve the co-ordination of productive facilities in Sheffield, Coventry, Birkenhead and Glasgow, across up to five companies, without an effective means of centrally managing the whole productive process. As Whittington highlights, 'networks need managing no less than hierarchies.'[21] Furthermore, Renneboog and Zhao have suggested that 'networks not only increase a director's influence but also bring additional skills, knowledge and information to the company.'[22] In terms of influence, three directors require attention: Charles Ellis, Bernard Firth and William Lionel Hichens, key figures at Brown, Firth and Cammell respectively. All command authority in their dealings with the COW board.

A key aspect of the COW network was the sharing and licensing of technical knowledge. Initial arrangements between Brown and Firth in 1903 emphasised the desire to exchange armaments technology. Bernard Firth is recorded as stating that Brown 'desired this Company [Firth] to give them information in reference to the manufacture of Gun Material.' Furthermore, it was ultimately agreed that the two Companies would 'give the fullest information and render every possible assistance to each other.' [23] Brown were aware that the acquisition of Firth would give them access to armour piercing projectiles, cast steel shell, and heavy marine steel castings, all materials required for their shipbuilding activities but previously purchased from outside sources.[24] Two further examples of knowledge sharing come from Firth's association with the COW partners. While not directly involved in the ownership of the company, their representation on the COW board of directors by Charles

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[20] J.F. Wilson and A. Thompson, *The Making of Modern Management: British Management in Historical Perspective* (Oxford, Oxford University Press, 2006) p.15.
[21] R. Whittington, 'Introduction: Comparative Perspectives on the Managerial Revolution', *Business History*, Vol.49, No.4 (2007), p.400.
[22] L. Renneboog and Y. Zhao, 'The Governance of Director Networks', in M. Wright, D. Siegel, K. Keasey, and I. Filatotchev, *The Oxford Handbook of Corporate Governance* (Oxford, Oxford University Press, 2013), p.211.
[23] Sheffield Archives (SA), X306/1/2/3/1/2, Firth's Directors Meeting Minutes, 20 March 1903.
[24] SA, X308/1/3/1/1, Brown's Secretary's Copy Letter Book No.4., 28 August 1902.

Ellis and Bernard Firth facilitated the licensing of their fuze designs to COW, and their projectile caps with Cammell. The royalties involved were small, Cammell paid Firth just £150 for caps in 1914, but such arrangements would have been more difficult without an already established network for communicating such possibilities.[25]

However, there were issues regarding the position of knowledge and experts within the network to best exploit their perceived value, such as with the Holmstrom breech mechanism. In 1905 after purchasing a half-share in COW, Brown established an ordnance department at their London offices and brought to the company Carl Albert Holmstrom, an expert in ordnance and gun design. Born and educated in Sweden, Holmstrom came to England in 1886 to work in the drawing office of Maxim-Nordenfeldt, before moving to China in 1895 as Vickers' technical representative. In 1901 he returned to England and took up a position as manager of Beardmore's ordnance department. By the time he joined Brown in 1905 Holmstrom had several patents to his name, and had invented a semi-automatic gun while at Maxim-Nordenfeldt in 1889. [26] An accomplished specialist in the field of ordnance, Holmstrom's appointment appears to not fit the armaments strategy of Brown at the time. His expertise and patent portfolio covered breech mechanisms of guns, a product not manufactured by the company. While at Brown, Holmstrom invented a new type of breech mechanism for medium calibre guns, a product whose special features were claimed to be '…the methods of obturation, safety, simplicity, reliability, case of manipulation and accessibility of working parts.'[27] Placed under the commercial control of Brown, the sole British licensees of the breech mechanism was COW, who had played a key part in the development of the mechanism and had covered the expense of its development while Brown paid Holmstrom's salary.[28] When the mechanism had been successfully tested, it was agreed by Bacon and Holmstrom that 'probably better financial results would be obtained if the arrangements for dealing with the rights for use of the Mechanism were in the hands of [Brown] rather than those of Coventry

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[25] Wirral Archives (WA), ZCL/5/56, Cammell's Sheffield Results, 1914, p.11.
[26] Institute of Mechanical Engineers 1915, p.806.
[27] SA, X313/5/1/1, Holmstrom Breech Mechanism for Medium Calibre Guns Technical Details, n.d., c.1910, p.1.
[28] SA, X313/1/2/1/2, COW Directors Meeting, 26 September 1907.

Ordnance Works.'[29] The reputation of Brown, who had more experience and connections in the international armaments market, was emphasised over COW and strengthened by retaining the employment of Holmstrom with Brown. Despite this potentially favourable marketing position, only the Greek Navy introduced the mechanism. In 1913 the Admiralty decided not to proceed any further with the breech mechanism after their trials.[30] By the time of his death in 1915, Holmstrom had obtained thirteen further patents related to ordnance since joining Brown.

In addition to the sharing of knowledge, COW also represented a means of sharing risk for the three partners. As Cammell discovered, entering into gun manufacture alone in 1903 was extremely demanding. By sharing ownership the risks could be distributed among them, but there were no guarantees of success. The COW network also facilitated the sharing of future risks, in particular the manufacture of aircraft.[31] In response to a War Office trial for military aircraft in 1911, the COW directors discussed commencing aircraft manufacture, without spending more than £5,500.[32] The decision was made to purchase the aircraft business of Howard Wright at Battersea in London, and employ Thomas Sopwith for two years as an aviator, who would receive half any prize money they might win in addition to his regular pay. An unnamed COW director wrote in early 1912 of aircraft manufacture:

> I favour the idea, however, not only because I think the business at any rate in its early stages will be a profitable one, but because I think it will be a valuable adjunct to any firm interested in Naval and Military manufactures.[33]

At the War Office trials in September 1912 the COW aircraft was unsuccessful, as it failed to lift the test weight more than 400 feet into the air.[34] However, COW was congratulated by War Office officials at Farnborough for the progress they had made in comparison to Vickers, who had invested ten times as much, and the Bristol Aircraft Company which had spent forty times as much as the

[29] SA, X313/1/2/1/5, COW Directors Meeting, 27 July 1910.
[30] SA, X313/1/2/1/8, COW Directors Meeting, 16 October 1913; Assistant General Managers Report 11 October 1913.
[31] On the British Aircraft Industry at this time, see D. Edgerton, *England and The Aeroplane* (London, Macmillan, 1991).
[32] SA, X313/1/2/1/6, COW Directors Meeting, 28 December 1911.
[33] SA, X308/1/2/1/10/1, Brown's Memoranda on Aircraft, n.d., 1912.
[34] SA, X313/1/2/1/7, COW Directors Meeting, 13 September 1912.

company for the trials.[35] Despite the partial success, Brown suggested that COW cease further expenditure on aircraft and discontinue the manufacture of aircraft at COW in November 1912, with Bernard Firth expressing the same opinion at a board meeting in December.[36] Despite these protests from one of the COW's parent companies, aircraft manufacture continued and the company received an order for six machines in early 1913, and a further 10 in June 1913. For the initial order, the estimated cost of manufacture for each was £240 with a selling price of £480, a 50% profit margin.[37] This was a potentially lucrative future market for armaments companies, and aircraft manufacture continued until the Great War at COW. In this case, the partner companies were willing to use COW to take a small financial risk with a new technology, and one which individually they would have been reluctant to take. Brown's reaction to the failure of the COW aircraft indicates that the company were more risk adverse away from their production of armour plate, and it is probable they would have never contemplated aircraft manufacture as an independent venture. As the largest shareholders in COW, Brown had attempted to exert influence over their fellow directors with limited success.

Reflecting on their diverse business holdings and ventures, Brown's management publicly stated in 1914 that they 'maintained the principle of decentralisation which had operated so successfully in their affiliated companies for so many years.'[38] This indicates that away from the management of their subsidiaries, Brown had an arms length approach to the day to day running of their investments. In 1914 Firth had accepted an order from COW for cast steel shields which required treatment in Krupp furnaces and had asked Brown for the use of their capacity at the Atlas works. After discussion at a Brown's Works Committee meeting, it was decided that:

> The general opinion was that Messrs. Firth should be assisted as much as possible, but, in view of the congested state of Krupp shop with the output of armour, it was advisable for Messrs. Firth to see assistance elsewhere.[39]

[35] SA, X313/1/2/1/7, Howard Wright to Reginald Bacon, 24 September 1912.
[36] SA, X313/1/2/1/7, COW Directors Meeting, 14 November 1912, 12 December 1912.
[37] SA, X313/1/3/1/2/1, COW Report of Commercial Reorganisation Committee, July 1913.
[38] *The Times*, 1 July 1914.
[39] SA, X308/1/4/1/1/2, Brown's Works Committee Minutes, 28 January 1914.

Brown had their own business to attend to, and were not prepared to facilitate Firth's requests. The principle of decentralisation had the potential to have an adverse impact on Brown's subsidiaries when they required more assistance than the parent company were prepared to offer.

While there were some managerial and control issues with the group, COW did eventually succeed in breaking the duopoly of Vickers and Armstrong for large calibre naval gun manufacture. In 1913, COW was 'fully recognised by the Government as an essential part of the national armament works', and was regarded as one of the most important suppliers for the Government, instead of being 'cold-shouldered' as they had been in previous years.[40] Their collaborative defensive action produced an armaments group more comprehensive than any individual company could offer, yet they suffered from being lower down the hierarchy of special relationships as outlined in the previous chapter. Overall, the development of COW provided the opportunity to share risks of entering new markets, establish a network for the communication of knowledge related to armaments, and as will be explored in the following section, the opportunity to collaboratively enter the international market for the companies involved.

Collaborative Approaches to International Markets

In addition to business relationships, the armaments industry also worked collaboratively in the international market. The use of foreign sales was a key strategy to counter the general uncertainty in the armourers' home market, continue to keep their plant in operation, and make a further return on their heavy research and development commitment. The British Government tended to look the other way when it came to armaments technology and its international transfer by the companies involved in developing it. Thomas Macnamara, Parliamentary and Financial Secretary to the Admiralty between 1908 and 1920, remarked to the House of Commons in 1914 that:

> All contracts that in any way comprise confidential matters contain strict stipulations in regard to the observance of the Official Secrets Act, and other necessary precautions. The Admiralty have no reason to doubt the adequacy of the steps taken in all matters that admit of being treated as

[40] *The Times*, 2 July 1913.

Government secrets or of being kept confidential in national interests. The Government does not interfere with the construction of armaments of contractors' design for foreign Powers, and cannot any more than any other Government necessarily monopolise all inventions and improvements, many of which from their nature could either not be kept confidential at all or only for a very limited period.[41]

When the armaments companies had foreign orders, their works remained in operation and they were not reliant on the British Government to provide orders to maintain such plant. During periods of 'slack' demand, as Trebilcock argues, 'the private armament sector could not afford to maintain its expensive and complicated plant in peak condition, in times of resumed demand, it could not afford *not* to do so.'[42] Foreign orders were therefore utilised to keep plant in operation. The result of being the most technologically advanced armaments centre in the world, and having a government favourable to the utilisation of such knowledge for foreign orders, was the international nature of the Sheffield armaments industry before the Great War. This aspect of the business also meant that private industry was a prime source of intelligence on foreign naval and military plans before 1918.[43]

Brown was the most active collaborator with other companies with foreign business. Their approach to international orders was 'to act alone' when 'the circumstances render it desirable, and, where co-operation is in our opinion necessary, to select the firm or firms to work with us who in our opinion are most useful for the purpose.'[44] With this in mind, Brown's association with both Vickers and Armstrong in two overseas markets requires further exploration.[45] In the international market, the grouping was a formidable one. As Trebilcock has observed they were:

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[41] Dr Thomas Macnamara to House of Commons, 8 April 1914, quoted from *The Iron And Coal Trades Review,* 24 April 1914, p.620.
[42] Trebilcock, *Vickers Brothers*, p.88.
[43] E.F. Packard, Whitehall, Industrial Mobilisation and the Private Manufacture of Armaments: British State-Industry Relations, 1918-1936 (London School of Economics, Unpublished PhD Thesis, 2009), p.80.
[44] SA, X308/1/2/1/10/1, Brown's Confidential Memorandum on Foreign Business, 28 August 1911.
[45] Such was the extent of Vickers' foreign investments that the company has been viewed as the first multinational enterprise. See R.P.T. Davenport-Hines, 'Vickers as a Multinational Before 1945', in G. Jones, *British Multinationals: Origins, Management and Performance* (Aldershot, Gower Publishing, 1986).

> Able to offer in one vessel, Armstrong hulls from the two yards at Elswick and Walker, Brown armour, and Vickers ordnance, mountings and engines, commodities separately of the highest international repute, here available in combination, this armourers' conclave could deliver a sales pitch which brooked few equals in overseas trade.[46]

The Brown-Armstrong-Vickers group would work together in Spain, assisting with the construction of the Spanish Navy, and in Turkey, where they built one battleship and received enquiries for three more, the possibility of building a floating dock, and providing assistance with the reconstruction of an arsenal in Constantinople. Prior to their association with Brown, Vickers and Armstrong had informal arrangements regarding royalties on foreign orders. Whichever company secured an order paid the other a proportion of profits, for example 2-3% of the cost of a ship hull and £6-10 per ton of armour. A confidential report at Vickers claimed the arrangement was necessary as without them 'competition between the two firms would reduce profits to vanishing point.'[47]

In Spain, Brown had entered the market in the 1890s and had suggested to their Minister of Marine that a number of British shipbuilders could work together to construct the Spanish Navy. Brown had discussed possible arrangements with both Vickers and Armstrong, but owing to the Spanish-American war in 1898 the plans were put on hold. When the market re-emerged Vickers approached Brown to join with them and Armstrong, and from 1908 they assisted in the formation of the *Sociedad Espanola de Construccion Naval* (SECN).[48] In 1911, Brown's Spanish naval work was described as a 'valuable adjunct to the Company's business,' and provided lucrative profits.[49] The three manufacturers agreed to supply SECN with all the armour required for three battleships, with prices set at the end of 1909 at £120 per ton. The specification agreed that KC armour would be used, and 'must be of the best quality used by

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46 Trebilcock, *Vickers Brothers,* p.125.

47 J.D. Scott, *Vickers: A History* (London, Weidenfeld and Nicolson, 1962), p.88. On Vickers' foreign business, see Trebilcock, *Vickers Brothers,* pp.119-141.

48 Scott, *Vickers*, p.84. On the spin-off benefits of the SECN, see C. Trebilcock, 'British Armaments and European Industrialization, 1890-1914', *Economic History Review,* Vol.26, No.2. (1973), p.254-272. For a more controversial view of the scheme, see R.J. Harrison, 'British Armaments and European Industrialization, 1890-1914: The Spanish Case Re-Examined', *Economic History Review,* Vol.27, No.4 (1974), pp. 620-624, and Trebilcock's response, 'British Armaments and European Industrialization, 1890-1914: The Spanish Case Re-Affirmed' in the same edition.

49 SA, X308/1/2/1/10/1, Brown's Confidential Memorandum on Foreign Business, 28 August 1911.

the British Admiralty at the time of the order of manufacture.'[50] During the 12 months commencing April 1910, Brown's works could produce a ton of KC armour for £70, with a selling price to the British Admiralty of £101, a 31 percent profit margin. By selling to SECN at £120 per ton, Brown was able to make a 42 percent profit margin on each ton of armour supplied. This was certainly a profitable extension to Brown's armour business. However, not every foreign contract the Browns-Armstrong-Vickers group acquired would be so rewarding for the company, as demonstrated by their ventures in Turkey.

In February 1910, the three companies signed an agreement for the Turkish battleship *Retshadeh*, which required Brown to supply one-third of the armour for the finished vessel that was being built at Vickers' Barrow shipyards. Vickers had agreed to build the vessel and engines at cost in order to secure the contact against fierce competition from other tenders, with Brown noting that 'the Contract is a very bad one both for ship and armament.'[51] The division of the order came under further scrutiny in February 1912, with Charles Ellis believing that Brown were due a proportion of the shell order to supply the battleship, to be supplied by Firth. After some correspondence with Vickers, their reply was rather blunt, stating that '…armament, including guns and ammunition, is divided between Armstrongs and Vickers, and Browns are not to have an interest in this item.'[52] The whole order ultimately proved of little value to Brown. Once the order had been delivered to Vickers in July 1914, Brown had produced 1,437 tons of armour, and received £82,210 of the £123,650 owed to them. Payments had begun for the armour in August 1911, and final payment was not received until 1915.[53] Even with the total paid to Brown, the amount they received would be £86 per ton of armour, a figure little above the cost of production, and well below the profit margin of producing for the Admiralty. Ultimately the order was for prestige rather than profit for the company. Brown knew this as well, and as early as 1911 acknowledged that

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[50] SA, X308/1/6/3/2, Agreement with Browns, Vickers and Armstrongs to supply armour to Sociedad, 1 November 1909.
[51] SA, X308/1/2/1/10/1, Brown's Confidential Memorandum on Foreign Business, 28 August 1911.
[52] SA, X308/1/3/1/3, Brown's Secretary's Copy Letter Book No.6., Elias Middleton to Hugh Calder, 3 February 1912. The resultant order for shell to supply the ship went to Hadfields in July 1913, ordered direct from Armstrong for 650 13.5 inch Heclon armour piercing projectiles, worth over £45,000. See below.
[53] SA, X308/1/3/1/3, Elias Middleton to Vickers' Secretary, 10 December 1914 and 2 March 1915.

their two partners continually secured the 'lion's share' of profitable work between them.[54] The company was the junior partner of the group, relied upon only for extra armour capacity when required for ship construction. In order to counter this, Brown looked to their COW partners to explore other foreign markets.

Brown's involvement with Vickers and Armstrong was due to arrangements made prior to the establishment of COW. Effectively, this had shut out the COW group from competing in Spain and Turkey:

> This may have seemed an advantage to us [Brown], but it has had the desired effect of closing every outlet in these countries for Coventry guns. The guns are what our rivals want, and as outside competition in every case reduces the hulls to little better than net cost, it is of comparatively small importance to them whether or not we get a hull at a low price or even a share of armour.[55]

In August 1911, an unknown Brown's director (presumably Charles Ellis), suggested the building of an armaments group solely for foreign business under the name of 'British and Foreign Naval Construction Syndicate.' This was in response to invitations from the Portuguese Government to re-equip their Navy. The group would consist of Brown, Cammell, COW, Fairfields, Palmer's Shipbuilding and Iron Co, and John I Thornycroft & Co.[56] It was suggested that:

> it would be in the interests of J Brown & Co, and of those other firms who are naturally desirous of securing at least a share of foreign government work, which Vickers-Armstrong group have almost entirely monopolised for so many years past.[57]

The aim was to attempt to gain a share of the foreign work which Vickers and Armstrong had for so long dominated, and Brown predicted that this would open serious competition with their two competitors 'in every country of the world.' The proposal for the syndicate was that it would be launched with a capital of £1million, establish a head office in London and divide all required work for foreign governments equally between the constituent companies. The idea was presented to Brown's board in early August 1911, and by the end of the month a provisional working arrangement had been made between the six companies

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[54] SA, X308/1/2/1/10/1, Brown's Memoranda as to Foreign Orders, 9 August 1911.
[55] SA, X308/1/2/1/10/1, Brown's Memoranda as to Foreign Orders, 9 August 1911.
[56] SA, X308/1/2/1/10/1, Brown's Memoranda as to Foreign Orders, 9 August 1911.
[57] SA, X308/1/2/1/10/1, Brown's Memoranda as to Foreign Orders, 9 August 1911.

which stated that only COW guns and mountings would be offered in Portugal.[58] The British and Foreign Naval Construction Syndicate went no further than working on Portuguese Naval orders, and no formal office was ever established in London. In 1913, with competition from a Vickers-Armstrong-Yarrow Shipbuilding Co group, the syndicate emerged victorious and secured orders for 12 vessels, including two cruisers for the Portuguese Navy.[59] Political issues in Portugal hampered progress being made, and no orders were placed before the Great War.[60] Other than this order, there were other attempts to pool resources for the international market by Brown. In November 1913 COW and the allied firms agreed to 'work together in respect of Naval or Military proposals in Greece, Bulgaria, Roumania [sic] and Brazil,' though the group failed to gain any orders.[61] Overall, with collaborative international orders Brown were a member of two groups of armourers, yet not fully incorporated or utilised in either. This had a serious effect on the company's ability to supplement their British Admiralty orders with financially rewarding foreign work, which could keep their armour plant going in times of slack demand. Away from collaboration with foreign orders, all the companies in the Sheffield armaments industry individually looked to the international market to further defend against the uncertainty of the arms industry.

Individual Approaches to International Markets

Collaboration was not always the most suitable approach to selling armaments in the international market. While the armour producers had experience of working collectively, both Brown and Cammell also worked independently to market armour and warships in the overseas market but achieved predominantly negative results. With projectiles, acting independently was a successful strategy for gaining lucrative orders from foreign governments, as will be demonstrated with the examples of Firth and Hadfields. Ultimately, the different fortunes of the Sheffield armaments industry in the international market varied with the two different products.

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[58] SA, X308/1/2/1/10/1, Brown's Confidential Memorandum on Foreign Business, 28 August 1911.
[59] *The Times*, 8 May 1913.
[60] SA, X308/1/2/1/10/1, Brown's Memorandum on Foreign Business, 30 June 1913.
[61] SA, X313/1/2/1/8, COW Directors Meeting Minutes, 13 November 1913.

Armour was a product rarely sold without being fixed to a new capital ship. Prior to the merger movement between 1897 to 1903 during which four previously independent shipbuilders became part of armaments companies, Vickers with the Barrow Shipbuilding Co, Armstrong with Joseph Whitworth, Brown with the Clydebank Shipbuilding Co and Cammell with Laird Brothers, foreign governments would choose a shipyard to build their new vessel, and a steel company to manufacture their armour. This process of vertical integration changed how armaments companies approached the sale of armour to foreign governments. Thereafter, armour had to be sold as part of a package which resulted in a finished vessel. In this regard, ship purchases were capital expenditures, a large one off cost for a product which all governments expected to be the most advanced possible at the time of purchase.

In the decade before 1903, Brown had amassed an impressive list of international customers, having supplied armour to Japan, Russia, Spain, Norway, Sweden and Holland.[62] The company also produced test plates for the Chilean government in 1902.[63] However, after amalgamation with the Clydebank Shipbuilding Co, the main constraint to Brown's sales of armour with foreign governments was a lack of warship contracts for their shipbuilding yards in the years before the Great War.[64] One area where Brown did extend their international links was through supplying ship designs and technical information to the Russian Baltic Shipbuilding Company in 1908. Three years later the company supplied an unknown Russian company technical assistance with the construction of two new battleships for the Black Sea Fleet.[65] While this was an important link, it was based on marine engineering technology, not armaments.

Undeterred, Brown continued to seek international customers, and in 1911 their Works Committee speculated over the possibility of receiving a number of foreign orders, including from Chile and China.[66] Expectations of orders in these markets had led management to invest in the expansion of the

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[62] Sheffield City Library (SCL), *John Brown and Company Limited,* 1903, pp.7-8. The testing of a Norwegian plate is detailed in *The Engineer*, 2 February 1900, p.124.
[63] SA, ESC Box 280, Brown's Managing Directors Reports, January 1902.
[64] SA, X308/1/2/1/10/1, Brown's Memoranda as to Foreign Orders, 9 August 1911.
[65] SA, X308/1/2/1/3/4, Brown's Managing Directors Report 29 September 1908; X308/1/2/1/10/1, Brown's Confidential Memorandum on Foreign Business, 28 August 1911. For an overview of Russian-British business links of the time, see G. Jones and C. Trebilcock, 'Russian Industry and British Business 1910-1930: Oil and Armaments', *Journal of European Economic History*, Vol.11, No.1 (1982), pp.61-103.
[66] SA, X308/1/4/1/1/1, Brown's Works Committee Minutes, 24 July 1911.

armour department at the Atlas Works, but the result was that neither country placed orders. In Chile the company had been working with Fairfield for the proposed construction of two battleships to utilise COW guns. They had been close to success, though the order was ultimately placed with Armstrong. The frustration of loosing the contract was reflected when one Brown director wrote:

> Our unfortunate experience in Chili [sic] shows that our agents may be duped and flattered up to the very last moment, when a more powerful influence comes in behind the scenes and deprives us of the expected results.[67]

However, at the Chilean Navy's request the battleship engines were supplied by Brown.[68] The company had a similar experience in China, where Brown had been working with Palmer's Shipbuilding Company to supply the ships ordered from their two shipbuilder yards, with armour from the Atlas Works and guns from COW, though the resulting order was placed with Vickers.[69] Also disappointing were attempts to open discussions for orders from Japan, Canada, Greece and Denmark in August 1911, but eventually no order was received from any of them. By 1913 the prospects for orders from foreign markets had evaporated, and Brown was focusing on their arrangements with other armaments companies.[70]

Cammell also struggled to gain foreign orders. The company never sold their projectiles outside of Britain, and international armour customers were small in number. They did secure an order from the Swedish admiralty for 722 tons of armour in 1900 at £110 per ton, but this turned out to be the last business in the country.[71] After amalgamating with Laird Brothers in 1903, Cammell took an ambitious approach to selling their ships in the international market. Vessels would be built without a firm order from a customer, and once construction entered the final stages the company would market the possibility of acquiring the vessel without the long wait for it to be assembled. The approach was entirely ineffective. In 1905 when two torpedo boat destroyers

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[67] SA, X308/1/2/1/10/1, Brown's Memoranda as to Foreign Orders, 9 August 1911.
[68] Warren, *Armstrongs*, p.143. Despite being a major naval constructor, Armstrong were reliant on outside sources for ship engines until they commenced their own manufacture after the Great War.
[69] SA, X308/1/2/1/10/1, Brown's Confidential Memorandum on Foreign Business, 28 August 1911.
[70] SA, X308/1/2/1/10/1, Brown's Confidential Memorandum on Foreign Business, 28 August 1911, Brown's Memorandum on Foreign Business, 30 June 1913.
[71] WA, ZCL/5/40, Cammell's Directors Meeting Minutes, 28 March 1900.

were nearing completion, Cammell contacted one of their European agents, Dr Adolf Rosendorff, to enter into negotiations with the Norwegian Government for their sale. The attempt proved futile, the Destroyers eventually sold to the British Navy. Rosendorff had been appointed by Cammell to explore the possibility of Russian orders, though his failure in Sweden led to his eventual dismissal.[72] The use of agents was a common approach in the industry, the most famous example being Sir Basil Zarharoff at Vickers. In 1904 Cammell attempted to use flattery with an intermediary from the Chilean Government when tenders had been invited for three armoured vessels. J.M. Laird contacted Jose Onofre Bunster, the Chilean representative in Liverpool, to ask him to take some sketches to Chile rather than post them. In a letter to Bunster, Laird wrote, 'as you know we for many years have had important and pleasant dealings with your Government and we are naturally desirous of continuing if possible on a larger scale with your Country.'[73] This approach, which placed an excessive emphasis on loyalty over technological prowess, also proved unsuccessful as no orders were received from Chile.

In 1906-7 tenders were explored for Portuguese gunboats and a Swedish battleship, though no orders were placed with the company.[74] Cammell's dismissal from the War Office and Admiralty lists in 1907 also had a disastrous effect on their ability to market their armaments to potential international customers. An enquiry from the Uruguayan Navy for a gunboat in November 1907 was certainly not finalised due to this. In requesting a return to the lists in 1908, new company chairman Sir Francis Elgar noted that 'foreign governments would not give them any work until they were rehabilitated.'[75] From this we can see that in lieu of advanced technology, marketing prowess or the use of an able team of overseas agents and salesmen, the major requirement for any foreign buyer was an assurance that the British Government was also a purchaser of the company's products. In essence, being on the lists of contractors in Whitehall was the key which opened the door to the international armaments market.

After Cammell returned to the British procurement lists, there were some attempts to re-enter the international market. Tenders were looked into for an

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[72] WA, ZCL/5/201/35, Rosendorff Agent File, 1905.
[73] WA, ZCL/5/201/33, J.M. Laird to Jose Onofre Bunster, 13 June 1904.
[74] WA, ZCL/4/5/16, Cammell Tender Book, 1906-1914.
[75] Warren, Steel, Ships and Men, p.131.

Argentine Battleship and Danish Torpedo Boat in 1909, though no orders were forthcoming. In the case of Argentina, only a pencil note appears in the Cammell Tender Book for the period, with none of the usual details such as speed, number of boilers and length present.[76] An agent was appointed by Cammell for Portuguese Navy orders in 1910, which gave the agent a 1% commission on battleships and cruisers, and 2.5% on destroyers and gunboats, all exclusive of armament.[77] Essentially, the agent would only gain a commission on the boat hulls, not the financially more lucrative armour, guns or gun mountings. Cammell may have needed the agents to help broker foreign orders, but they were not prepared to excessively reward them financially for their sale of these high-capital products. A collusive arrangement was also explored with Vickers in an attempt to almost force the Italian Government into placing an order with Cammell. Vickers had agreed to quote higher than Cammell, stating they were 'very pleased in this instance to assist you get Italian Contract.' Their instructions to Cammell were:

> When making up your price, please include £1,000 for us which you will pay to us in the event of the order being placed with you…When your price is made up, please send it on to us, and we will take good care to quote a price in excess, so that so far as our competition is concerned, you need have nothing to fear.[78]

No further record of this transaction has been found, suggesting that Cammell were unsuccessful with the Italian Government. However, the suggestion that Vickers would purposely sabotage their ability to profit from another foreign customer in order to help re-habilitate a home competitor into the international market demonstrates one aspect of the collaboration Sheffield armourers had. The only successful international order undertaken by Cammell in this period was for four torpedo boat destroyers for the Argentine Navy. Ordered in 1910, the Argentine programme was for 12 destroyers in total, four were ordered from two German companies, four from two French companies, and the final four from Cammell. By the time of their delivery in 1913, the Argentine contract had been annulled and the vessels Cammell had built were sold to the Greek

[76] WA, ZCL/4/5/16, Cammell Tender Book, 1906-1914.
[77] WA, ZCL/5/201/34, R.R. Bevis to A.M. Dos Santos, 30 March 1910.
[78] WA, ZCL/5/201/39, Vickers to R.R. Bevis, 19 December 1911.

Navy.[79] Aside from arrangements with other armaments Companies for supplying the Portuguese Navy, Cammell failed to attract any other foreign orders before the Great War. The variety of approaches to securing overseas orders highlights the value the company saw in foreign business, with ultimately little reward.

In contrast to armour, the selling of projectiles to international customers was more successful. These were a product with elastic demand, used for training in peacetime and required in greater numbers with every new capital ship. Once rendered obsolete by technological advances, they could be replaced by an updated design, resulting in more orders for the projectile manufacturers. Replacing the armour on a ship would be nigh on impossible if a new method of production was introduced. Buying a new ship was the usual option rather than a vast overhaul. The standardisation of armour production to Krupp Cemented (KC) plates, facilitated by the Harvey United Steel Company, also aided the marketing of projectiles in the international field. As the majority of the world's navies purchased ships built with KC armour after its introduction, conformity in the ability of the armour made selling the capability of a projectile to defeat the most common type of armour a key marketing point. Any projectile which could perforate KC armour could defeat any navy in the world. The use of brand names like Heclon and Rendable made differentiation between Hadfields and Firth products simpler, as the performance of the two companies AP projectiles was comparable. To aid marketing projectiles to international customers, both also entered into agreements with cordite firms specifically for overseas business, and Firth had commenced the manufacture of their Hoyle and Strange fuzes to offer a complete package. As their marketing materials pronounced, Firth were able to supply 'Projectiles charged and ready to fire', to a foreign customer. Once the British Navy introduced the new AP projectiles, both companies were predominantly reliant on the Admiralty for orders at home. The Army ordered far fewer projectiles than the Navy, and as will be demonstrated, for Firth and Hadfields the increase in their international customers from 1906 would be more lucrative for them than those for the British Army.

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[79] *The Engineer,* 18 July 1913, p.59.

At Firth, the company was able to attract a number of international customers between 1906 and 1913, and the comparison with orders for the British Army is shown in Table 4.2. The Greek Government placed orders with Firth annually between 1911 and 1913, and the Danish Government placed their single order in 1910.[80] Orders received from the Spanish Government had been agreed by Charles Ellis as part of the SECN with Vickers and Armstrong, Firth receiving orders for one third of the projectiles required.[81] No details of the financial value of the Spanish orders are available. However, these ordered were on the whole small compared to Firth's pre-eminent foreign customer, the Italian Government, which requires further exploration.

Table 4.2: Firth's Foreign Customers for Projectiles 1906-1913

Customer	Value (£)
Italian Government	504,116
Greek Government	106,000
Danish Government	17,000
Spanish Government	Unknown
British Army	6,625

Source: Calculated from Firth's Directors Records, Firth's Reports to Brown's Board, 1906-1913

After submitting projectiles to a firing test in 1906, Firth received a contract from the Italian Government, which stipulated that a major portion of the order had to be fulfilled in Italy.[82] In order to complete the order, Firth were faced with the decision to either establish their own overseas works in the country, which would have been in addition to their already established shell manufacturing in America and Russia, or go into partnership with another company. Given the quick delivery required for the order, Firth chose the latter, working with Armstrong to utilise the Armstrong Pozzuoli Works which had been established in the 1890s.[83] From the arrangement, Armstrong would be paid one third of the overall value of the order of £130,000, Firth receiving the

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[80] SA, X308/1/2/1/4/5-8, Firth's Report to Brown's Board 5 April 1910, 31 October 1911, 29 October 1912, 25 February 1913.
[81] SA, X306/1/2/3/1/3, Firth's Directors Meeting Minutes, 30 March 1909.
[82] SA, X306/1/2/2/1/1, Firth's General Meeting Minutes, 30 April 1907.
[83] SA, X306/1/2/2/1/1, Firth's General Meeting Minutes, 30 April 1907. On Armstrong's Italian works before the Great War, see Warren, *Armstrongs Of Elswick*, Chapters 11 and 16. No mention is made by Warren of Armstrong's links with Firth at the Pozzuoli Works.

balance of two thirds. This initial order initiated the beginning of a relationship with the Italian Government which helped supplement Firth's shell output until the Great War. At the end of 1906, Firth's Gun Works had £155,000 of orders on their books, of which £113,000 was for Italian projectiles. In other words, almost three quarters of the work the Gun Works had in hand was for a foreign customer. This clearly demonstrates the value of overseas customers to Firth, especially with an absence of British orders in 1906 and 1907 as discussed in the previous chapter.

Table 4.3: Firth's Italian Shell Orders, 1906-1913

Year	Total Orders Received (£,000s)
1906	130
1907	*No orders*
1908	18
1909	71
1910	*No orders*
1911	222
1912	14
1913	9

Source: Firth Records, Firth's Reports to Brown's Board, 1906-1913

The first order from Italy was followed by a string of orders over the next seven years, as shown in Table 4.3. All of these were for six to 13.5 inch AP projectiles, allowing Firth to utilise their advanced armaments technology and further profit from their research commitment. Overall, Italian shell requirements helped to maintain the Gun Works in production and allowed Firth to maintain their skilled staff. The orders received from the Italian Government in 1911 were more than double those received from the British Government in the same year, and were expected to yield a 20% profit.[84] International customers, especially the Italian Government, were central to Firth's ability to keep their shell plant running in the decade before the Great War. Additionally, the Italian Government were also open to the use of new projectile technologies developed at the company. For example, a small order placed in 1913 was for

[84] SA, X306/1/2/3/2/115, Firth's Directors Meeting Papers, 30 January 1912.

Firth's new type of oblique caps to replace older designs already fitted to projectiles supplied to the Italian Government. These oblique caps underwent testing and entered service in Italy during 1915, ahead of the British Government's utilisation of the technology.[85]

Connections to the Italian market were obviously important to the company, but Firth also attempted to sell its projectile technology and productive expertise in other overseas markets before the Great War, with less success. In 1907, Hoyle endeavoured to gain an order for AP projectiles in Japan in 1907, but the order was lost to Hadfields.[86] In 1911 Firth received enquiries from a Hungarian company regarding licensing their process of projectile manufacture, which proceeded no further.[87] A suggestion was also put forward at the end of 1913 by Major Strange regarding a proposal to form an Ordnance Company for the Balkan States, which also did not come to fruition.[88] Firth had also explored a 'worldwide arrangement on projectile matters' with Hadfields at the suggestion of Robert Abbott Hadfield in 1911, but no further negotiations took place.[89] With each case Firth were searching for further ways to financially benefit from their commitment to armaments research, in addition to their lucrative orders from the Italian Government. The negotiations for foreign orders were difficult and yielded little success with new customers, but when important connections were made these could continue to pay dividends, as Hadfields also found with their business in Japan.

Hadfields, who had also experienced difficulties in dealing with a monopsonist buyer between 1907 and 1911, knew they also could no longer rely on the Government for sufficient orders to maintain projectile production and retain their skilled labour force. Following the collapse of Army orders, as a means of supplementing the firm's work for the Navy and to keep their productive facilities working, from 1908 Robert Hadfield began actively seeking foreign orders for his projectiles. The company had produced projectiles for the United States government in the 1890s, and foreign orders had been placed from 1904 onwards, but these had mostly been small orders. By 1912, Hadfields' list of international customers included the United States

[85] SA, X308/1/2/1/4/8, Firth's Report to Brown's Board, 28 July 1913; SCL, *The Evolution Of The Modern AP Projectile,* 1924, p.9.
[86] SA, X308/1/2/1/4/2, Firth's Report to Brown's Board, 26 March 1907.
[87] SA, X306/1/2/3/1/3, Firth's Directors Meeting Minutes, 28 March 1911.
[88] SA, X306/1/2/3/1/4, Firth's Directors Meeting Minutes, 23 December 1913.
[89] SA, X306/1/2/3/1/4, Firth's Directors Meeting Minutes, 31 October 1911.

Government, Japan, Italy, France, Russia, Spain, the Argentine Republic, Chile and Brazil.[90] Despite this impressive list of customers, lucrative orders were not regularly received from foreign governments, with some customers only placing one order with the company. For instance, the Spanish Government ordered 1,000 armour piercing projectiles between 1904 and 1906 totalling over £9,000, with no further orders placed.[91] The Italian Government ordered a total of 32 Heclon and Eron shells in 1906 worth £372,[92] and the French Government ordered in 1912 just 10 six inch Heclon projectiles valued at £70.[93] Not all orders were for the most technologically advanced shells either; the Argentine Navy ordered 11,100 practice shells between 1909 and 1912, worth around £1 per shell,[94] and the Greek Government ordered 600 larger calibre practice projectiles in 1914 worth £1,649.[95] This impressive list of international customers for projectiles and war materials, in conjunction with being a supplier for the British Government, were important selling points for the majority of these products in new foreign markets. In many of Hadfields' overseas markets the company recorded only small and irregular orders, but in the lucrative American and Japanese markets the company could command more profitable and regular sales for its products. Of key importance here were the US Navy and Imperial Japanese Navy (IJN) requirements after 1909, detailed in Table 4.4.

In July 1911 Hadfield welcomed Admiral Togo and representatives of the Japanese Government for a tour of the East Hecla Works, and in the same year he also personally negotiated contracts with US Army and Navy.[96] Rather than utilise overseas agents or instruct his directors to travel across the Atlantic to deal with these orders, Hadfield wanted to receive the adulation for his achievements first hand. Not only could he show off his projectiles, he would be able to personally negotiate the contracts and as a result take pleasure in the esteem associated with signing such an order with the US Government. The US

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[90] SCL, The Hadfield System As Applied To War Materials, n.d., probably 1912, p.7.
[91] SA, Hadfields Volume 151, Projectile Orders No.1, p.157, 2 August 1904, and p.219, 21 April 1904.
[92] SA, Hadfields Volume 151, Projectile Orders No.1, p.221, 22 May 1906, and p.253, 22 October 1906.
[93] SA, Hadfields Volume 152, Projectile Orders No.2, p.66, 14 April 1912.
[94] SA, Hadfields Volume 151, Projectile Orders No.1, p.331, 13 December 1909, and Volume 152, p.60, December 1912.
[95] SA Hadfields Volume 152, Projectile Orders No.2, p.129, 21 January 1914.
[96] SA, Hadfields Volume 93, Hadfields Board Minutes No.2 1904-1936, p. 93, May 9th 1911, and p. 112, November 7th 1913.

Army and Navy ordered their first Heclon AP shells in 1909, a total of just 41 between the two services for testing and evaluation.[97] The first major order, negotiated personally by Hadfield in the US, came in 1911 for 100 14 inch Heclon AP shells, worth just over £9,000 for the US Army, followed in 1912 by an order for 500 12 inch Heclon AP shells for the US Navy, worth £19,000.[98]

Table 4.4: Hadfields' Foreign Projectile Orders 1909-August 1914

Customer	Total Order Value
Imperial Japanese Navy	£476,146
United States Government	£34,903[99]
British Army	*£31,291*
Argentine Navy	£10,786
Greek Government	£1,649
French Navy	£70

Source: SA, Hadfields Projectile Orders No.1, Volume 151, and Hadfields Projectile Order No.2, Volume 152.

In comparison to the US Government, the IJN would place far more extensive orders. After their initial order in 1909 for 800 12 inch and 800 10 inch Heclon AP shells worth £40,000, the IJN continued to order from Hadfields year on year with a string of lucrative orders, shown in Table 4.5. These orders were predominantly for the Heclon AP projectile, supplemented with the Eron after the IJN introduced the projectile in 1912. After two years of successful orders, in 1911 Hadfields and the IJN entered into an agreement which, in contrast to their agreements with the British Government, promised a minimum order value over the course of the following four years. The Japanese agreement promised Hadfields orders for projectiles valued at £320,000 over four years from March 1911, with the added clause that both orders and deliveries totalled £75,000 to £85,000 per year. Additionally, the agreement only covered the Heclon and Eron projectiles.[100] The contract was a much more stable one than those with the British Government, whose promise of a proportion of orders could result in few being placed in time of slack demand, as Hadfields had found in the years

[97] SA, Hadfields Volume 151, Projectile Orders No.1, pp.315-316, 9 August 1909.
[98] SA, Hadfields Volume 152, Projectile Orders No.2, p.59, 25 November 1911, and p.98, 12 November 1912.
[99] The United States Army and Navy ordered separately from Hadfields. Army orders 1909-August 1914 totalled £9,548, Navy orders £25,355
[100] SA, Hadfields Box 66, Hadfields-IJN Agreement, 1911.

since their agreement had been signed with the Admiralty and War Office in 1905. Through this agreement Hadfield had secured his own 'irreducible minimum', albeit from a foreign government, which ensured that the Hecla Works and workmen would be kept active at a minimum level for the following four years, independent of orders from the British Government. As a result of this series of large orders, by the time of the Great War the IJN had become a larger customer for Hadfields than the British Army.

Table 4.5: Hadfields' Imperial Japanese Navy Orders 1909-August 1914

Year	Total Orders Received
1909	£40,000
1910	£62,191
1911	£87,274
1912	£114,153
1913	£79,664
1914 (To August)	£92,864

Source: SA, Hadfields Projectile Orders No.1, Volume 151, and Hadfields Projectile Order No.2, Volume 152.

The Ottoman Empire was also considered a potential major customer for Hadfields from 1913. Their first order had come via Armstrong, who in collaboration with Vickers had been tasked with equipping the Ottoman battleship *Reshadieh,* which was nearing completion at Vickers' Barrow shipyard. The order was for 650 13.5 inch Heclon AP shells, worth £45,000. This was followed by an order to Hadfields direct from the Ottoman Empire in April 1914 for 2,353 projectiles worth £39,700 to equip another naval ship.[101] Due to the outbreak of the Great War, only the initial order would be fulfilled with no work undertaken on the latter.[102] Had the second order been fulfilled, and followed by further orders, then the Ottoman Government could have been

[101] SA, Hadfields Volume 152, Projectile Orders No.2, p.136, 2 April 1914.
[102] The *Reshadieh,* along with the *Sultan Osman I,* would be seized by the British Government in August 1914 due to the outbreak of the Great War due to a British fear it would be used to support to Central Powers. This incident would be cited as one of the reasons for the Ottoman entry into the Great War, as the *Reshadieh* was seized one day after the final payment was made from the Ottoman Government. The total £4million cost had been paid for mostly by public subscription in the Ottoman Empire. The *Reshadieh* was renamed HMS Erin. See Scott, *Vickers*, p.110. Scott records how the ship order almost went to Krupp, and Vickers had secured the contract at the last moment.

second to the Imperial Japanese Navy of Hadfields' most lucrative foreign customers.

By the outbreak of the Great War, Hadfields were making substantial returns on their investment in developing projectile technologies, and had been for the prior four years. Through agreements with the British Navy and IJN, along with their extensive list of overseas customers, the company had become perhaps the most prominent supplier of projectiles anywhere in the world.

Conclusion: The Sheffield Armaments Industry in 1914

The defensive measures Brown, Cammell, Firth and Hadfields engaged in were a common factor of the Sheffield armaments industry before the Great War, as each attempted to counter the uncertainty of British Government demand for their core armaments products. The establishment of the COW and its inter-company management structure created a network of directors and productive capabilities, and facilitated the sharing of knowledge and risks related to technology. The Coventry network also provided an opportunity for the companies involved to engage in the international armaments market as a group, though with limited reward. The only successful, though strained, collaborative arrangement in the international market was that of Brown with Vickers and Armstrong. Elsewhere, each armament company individually looked at the international market as a lucrative outlet for their products, and as a means of countering inconsistent Government demands. However, selling armaments to foreign governments proved as difficult as selling in their home market, with no guarantee of success. Individually, the projectile manufacturers fared better than their armour producing counterparts. Firth had managed to capture the Italian market, though Hadfield's relationship with the Imperial Japanese Navy was the most secure armaments supply arrangement made by any company before the Great War.

These collaborative and international activities were part of a vast web of arrangements made by the Sheffield armaments industry by the outbreak of the Great War. All of these technological, business and international arrangements are show as they existed in 1914 in Figure 4.2. When hostilities began, the Sheffield armaments industry was at its zenith. As Tweedale has rightly highlighted, 'On the eve of the First World War, the leading European arms makers…had largely been surpassed by Sheffield.'[103] The complex and overlapping arrangements developed by the participants since 1900 had made Sheffield the world centre of armaments and metallurgical developments. Additionally, it was one of the most important areas of projectile and armour production, supplying British and foreign governments. On the eve of War, Sheffield was undoubtedly the 'Arsenal of the World.' However, the Great War affected the nature of the armaments industry, especially with regards to the development and protection of the technology involved. This change and its repercussions through to the end of the 1920s, including the emergence of the special steel industry in Sheffield, are explored in the following chapter.

[103] G. Tweedale, *Steel City: Entrepreneurship, Strategy and Technology in Sheffield 1743-1993* (Oxford, Clarendon Press, 1995), p.103.

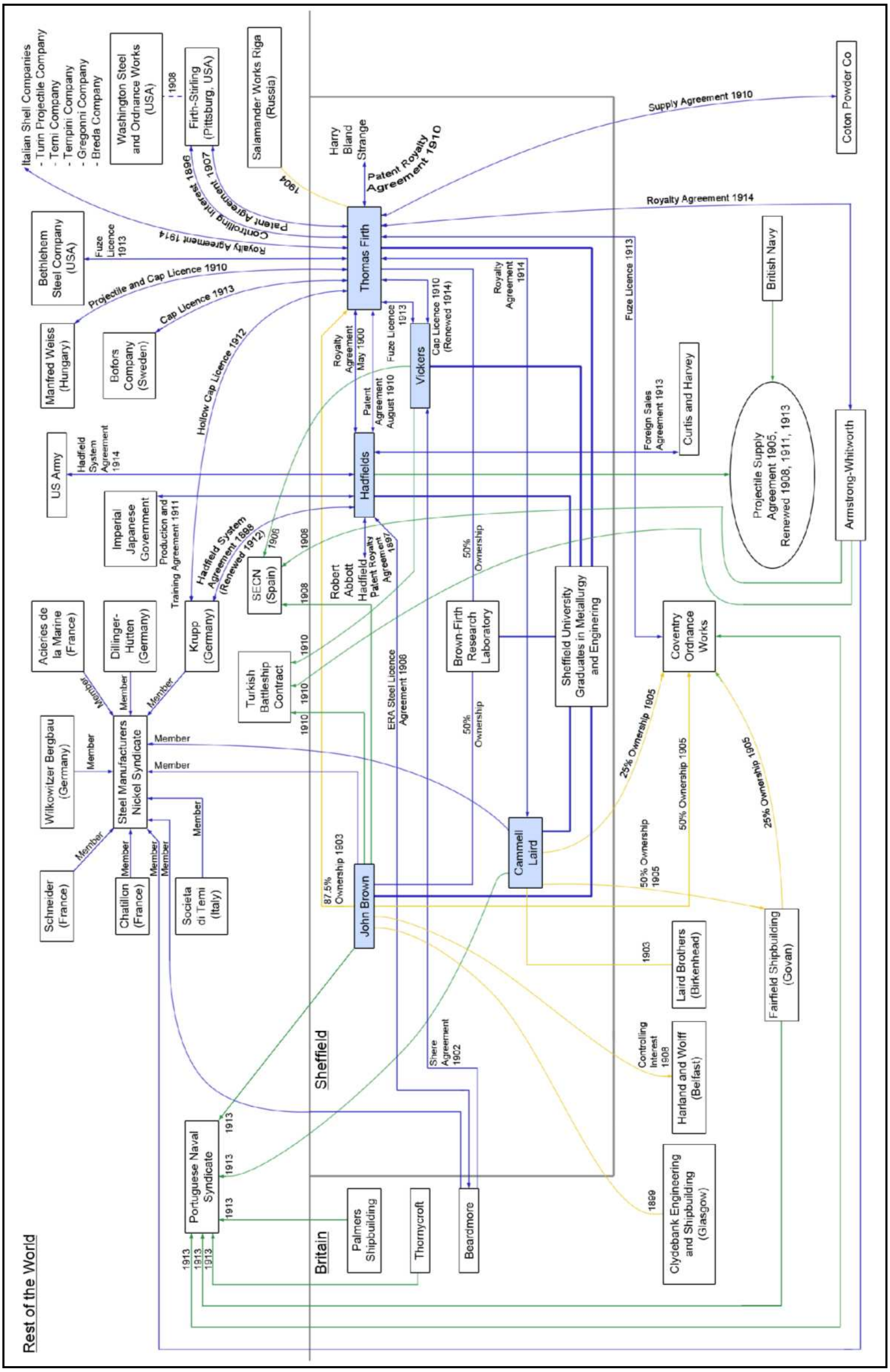

Figure 4.2: The Sheffield Armaments Industry in 1914

Chapter 5: Technological Development in War and Peace 1914-1930

Before 1914, the armaments industry's output was primarily focused on supplying the British Admiralty as part of a vast naval-industrial complex, the paradox being that the Great War would be dominated by supplying the Army as part of a European land war.[1] Even with the need for increased volumes of war material and a change in procurement strategy following the formation of the Ministry of Munitions in 1915, the armaments companies remained defensive of their position as custodians of the knowledge they had developed and financially invested in. Examining the development of armaments technology during the Great War and the 1920s, this chapter will examine three key areas. Firstly, there will be an exploration of the technological activities of the armament companies during the Great War. This will focus on three areas of investigation; the expansion of productive capabilities and the creation of a collaborative network for utilising the machinery available to them; the albeit reluctant collaborations with local manufacturers and the training provided in the production of shells; and finally the innovative developments made with armaments technology in wartime. Each of these will be considered as a new form of defensive mechanism, different to those implemented prior to the Great War. The new defensive measures executed during the conflict were a means of protecting each company's status as an armaments producer in a period of unparalleled demand and general industrial mobilisation. The second section of the chapter will explore the development of AP projectiles following the Battle of Jutland, and the research arrangements made between Firth and Hadfields in seeking progressively more practical than metallurgical solutions. Finally, the chapter will consider the evolving relationship between armaments development and metallurgy during and after the Great War, and the rise of the alloy steel industry in Sheffield.

[1] For a general overview of business and the Great War, see R. Lloyd-Jones and M.J. Lewis, *Arming the Western Front: War, Business and the State in Britain 1900*-1920 (London, Routledge, 2016).

Armaments Technology and the Great War: Production, Training and Innovation

The Great War by 1915 was a 'war of machinery', requiring the mobilisation of vast amounts of British industrial capacity for munitions production to supply an ever increasing demand for artillery shell.[2] As the British Army grew from 30 divisions in August 1914 to 70 by the summer of 1915, the Government's solution was to 'simply increase the volume of its contracts, reproducing the 'unruly torrent' of orders that had crashed down on the private armouries in 1899.'[3] On 17 September 1914 alone Hadfields received 20 separate orders for 106,000 shells and projectiles.[4] The Boer War had demonstrated that 'the private armourers tended to produce both extravagant promises and inadequate deliveries early in the war and then to improve their performance as it progressed.'[5] This was certainly the case as projectile manufacturers in Sheffield took on orders far beyond their productive capabilities from August 1914. For their part, the private manufacturers operated under the notion of 'business as usual' and failed to anticipate the scale of the conflict to come.[6] Before the War, the armaments manufacturers had acted defensively in order to protect their status in the industry, and to secure international customers as orders from the British services were not sufficient to keep their plant running. As orders flooded in they had a new and unknown issue; what to do with too many orders. By mid-1915 with the establishment of the Ministry of Munitions and a change in procurement strategies, the armourers again acted defensively to maintain their position as the core of the industry and as the technological custodians of the industry once peace came.

As demand outstripped capacity, the projectile manufactures frantically increased their productive capabilities. Firth began to expand their shell capacity from September 1914, and by December had been asked to modify

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[2] R. Lloyd-Jones and M.J. Lewis, '"A War of Machinery": The British Machine Tool Industry and Arming the Western Front, 1914-1916' *Essays in Economic and Business History,* Vol.26, No.1 (2008), pp.117-8.

[3] C. Trebilcock, 'War and the failure of industrial mobilization: 1899 and 1914' in J.M. Winter, *War and Economic Development, Essays in the memory of David Joslin* (Cambridge, Cambridge University Press, 1975), p.154. For a general overview of industrial mobilisation across Europe during the early months of the War, see H. Strachan, *The First World War Volume 1: To Arms* (Oxford, Oxford University Press, 2003), Chapter 11: Industrial Mobilisation.

[4] Sheffield Archives (SA), Hadfields Volume 153, Hadfields Projectile Orders No.3.

[5] Trebilcock, Mobilisation, p.152.

[6] On business as usual, see R. Lloyd-Jones and M.J. Lewis, *Arming the Western Front: War, Business and the State in Britain 1900*-1920 (London, Routledge, 2016), pp.79-81.

their Tinsley Works for the manufacture of shell for Army requirements.[7] Three shell plants were installed, for 5 inch, 7.5 inch and 9.2 inch high explosive projectiles.[8] New machinery was also installed at the Gun Works in early 1915 for 60 pounder and 8 inch high explosive shell for the Army, and 6 inch high explosive shell for the Admiralty.[9] Cammell over the course of the war expanded their shell shops from 30,000 to 200,000 square feet of floor space, and increased their workforce from 160 to over 3,000.[10] By September 1915 Hadfields had installed new plant for the production of 9.2 inch, 4.5 inch, 60 pounder and 18 pounder high explosive shells for the Army, 15 inch and 9.2 inch high explosive and 6 pounder anti-aircraft shell for the Navy, and expanded their AP projectile plant.[11] The War also provided an opportunity to further profit from projectile technology. In September 1914 Firth licensed their hollow cap patents to Vickers in return for small royalties and the condition that all caps were stamped 'Firths Patent'.[12] The same technology was licensed to the Italian Breda Company in December 1914, requiring two payments of £2,000 to be paid in addition to royalties.[13] Hostilities failed to change the core aspect of international technological exchange in the armaments industry.

Despite expanding production, Admiralty and War Office targets failed to be met. By May 1915 Hadfields had delivered 20,000 shells out of 32,000 promised, a shortfall of 27 percent. Firth, even with their expanded capacity, faired even worse. The company had delivered 17,450 out of 71,300 promised by May 1915, a little over a quarter of the total.[14] These figures would be a prelude to the Shell Crisis in the spring of 1915 and the formation of the Ministry of Munitions, whose principal aim would be to utilise the whole of Britain's industrial capacity for the production of the full range of supplies for the British

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[7] SA, X306/1/2/3/2/147, Firth's Directors Meeting Agendas and Papers, 1 September 1914; X308/1/2/1/4/9, Firth's Report to Brown's board, 1 December 1914.
[8] SA, X306/1/2/3/2/166, Firth's Directors Meeting Agendas and Papers, 1916.
[9] SA, X308/1/2/1/4/10, Firth's Report to Brown's Board, 27 April 1915.
[10] 'The History of Cammell Laird' in *Sun and Agricultural Journal of South Africa,* February 1920, p.48.
[11] SA, Hadfields Box 57, Visit of his Majesty the King to the East Hecla Works of Hadfields Ltd, Sheffield, 29 September 1915, p.2.
[12] SA, X306/1/2/3/1/4, Firth's Directors Meeting Minute Book No.4., 1 September 1914, p.214, X306/2/3/3/2, Agreement For Firths Hollow Caps with Vickers, 2 September 1914.
[13] SA, X306/1/2/3/1/4, Firth's Directors Meeting Minute Book No.4., 1 December 1914, p.225.
[14] The National Archives (TNA), T181/71, Royal Commission on the Private Manufacture of and Trading in Arms, Abstract of evidence relating to Hadfields, Firths, Beardmore and Birmingham Small Arms, 1935.

Army.[15] Against this backdrop, the armaments companies in Britain collaborated with the Ministry where possible, but were acutely aware of the need to defend their position as armaments manufacturers and the skills and knowledge they had developed before the War. The three projectile manufacturers all undertook the running of National Projectile Factories from late 1915, Cammell establishing a works at Nottingham, Firth at Templeborough, and Hadfields within the East Hecla Works in Sheffield, all of which drew on newly mobilised female labour.[16] Robert Abbott Hadfield, while accommodating, requested the Government keep a distance from their developments, asking in October 1915 that 'may we beg that as little red-tape and routine work be imposed upon us as possible' and stating to the Ministry of Munitions that:

> Both I and Mr Jack have trained up our people in our own way, and we venture to think the results have not been unsatisfactory for the Army and Navy Services. To interfere with us at the present time is surely not a good policy. <u>We will give you what you want, that is an immense supply of shell, </u>only do not let us be worried too much. Our past records show what we have accomplished.[17]

It was a simple message; Hadfield and his company would co-operate, so long as interference from the government was avoided. They were the experts in the field, not the Ministry of Munitions. In this regard the Ministry would benefit from the 'development work of the experts within the private armaments firms.'[18]

As Hadfields, Firth and Cammell all increased production of shells, a product which they were all familiar with, Brown diversified into projectile manufacture for the first time by utilising their productive facilities in a more

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[15] On the Ministry of Munitions, see R.J.Q. Adams, *Arms and the Wizard: Lloyd George and the Ministry of Munitions 1915-1916* (London, Cassell, 1978); C. Wrigley, 'The Ministry of Munitions: an Innovatory Department' in K. Burk, *War and the State: The Transformation of British Government, 1914-1919* (London, George Allen and Unwin, 1982); R. Lloyd-Jones and M.J. Lewis, *Arming the Western Front: War, Business and the State in Britain 1900*-1920 (London, Routledge, 2016); and the 12 volume *Official History of the Ministry of Munitions.*

[16] S. Pollard, *A History of Labour in Sheffield* (Liverpool, Liverpool University Press, 1959), p.271. Female workers were introduced to armaments work in Sheffield under the 'Shells and Fuzes' agreement of 4 March 1915 which permitted women and youths work on repetitive jobs and to substitute some men on semi-skilled jobs. On the origins of the National Projectile Factory scheme, see R.J.Q. Adams, *Arms and the Wizard: Lloyd George and the Ministry of Munitions 1915-1916* (London, Cassell, 1978), pp.68-9.

[17] TNA, MUN 4/83, Sir Robert Abbott Hadfield to Sir Frederick Black, 8 October 1915. Emphasis in original document.

[18] Adams, *Arms and the Wizard*, p.148.

dynamic way.[19] Production commenced with an order for 2,000 15 inch howitzer shells for the Coventry Ordnance Works in September 1914. The order had initially been placed with Firth, who could not accommodate it due to increased demand from the War Office.[20] During the same month, Brown had explored using the same facilities for producing 12 inch and 15 inch common shell.[21] Any possible expansion of armaments production was considered, the opinion of Brown's Works Committee being that 'the Company should hold itself at the service of the Government, providing satisfactory financial terms were arranged.'[22] One enquiry received in late 1914 from the War Office asked Brown to begin production of high explosive shell. While considered desirable by Brown's directors, the estimated £100,000 required for establishing a shell shop meant the scheme was ultimately rejected, another productive option proving more suitable and less financially draining.[23]

Shortly after the establishment of the Ministry of Munitions, Bernard Firth highlighted to his fellow Brown's directors that 'the crux of the difficulty in the supply of shells would rather be in the supply of suitable steel for shells than in the manufacture or machining' and strongly suggested that the company would be better equipped in this area instead of machining shell.[24] Negotiations with the Ministry of Munitions commenced in December, and Brown agreed to convert their armour plate mill for the production of large shell bars with an estimated output of 300 tons per week, the alterations and additions costing £15,000.[25] Work on converting the works began in November 1915 with production beginning six months later for 12 inch and 15 inch shell bars.[26] The bars were supplied to four companies for shell manufacture; Walter Somers and Co Ltd near Birmingham, the Darlington Forge Co, the Earl of Dudley's works, and to Hadfields who specialised in producing 15 inch high explosive shell.[27] The conversion caused issues for Brown when new armour orders were placed in August 1916. Their entire Siemens furnace output was for the production of

[19] On dynamic capabilities see D.J. Teece, G. Pisano, A. Shuen, 'Dynamic Capabilities and Strategic Management', *Strategic Management Journal*, Vol.18, No.7 (1997), pp.509-533.
[20] SA, X308/1/4/1/1/2, Brown's Works Committee Meeting Minutes, 28 September 1914.
[21] SA, X308/1/2/1/10/1, A.W. Dixon to Chairman and Directors of Brown, 27 October 1914.
[22] SA, X308/1/4/1/1/2, Brown's Works Committee Meeting Minutes, 26 April 1915.
[23] SA, X308/1/4/1/1/2, Brown's Works Committee Meeting Minutes, 30 November 1914.
[24] SA, X308/1/4/1/1/2, Brown's Works Committee Meeting Minutes, 26 July 1915.
[25] SA, X308/1/2/1/3/11, Brown's Managing Directors Report, 2 December 1915.
[26] SA, X308/1/4/1/1/2, Brown's Works Committee Meeting Minutes, 20 November 1915, 30 May 1916.
[27] TNA, MUN 4/4273, John Brown Shell Billets file, 1916-1917.

shell steel, and problems were foreseen in reducing the output with the Ministry of Munitions.[28] An arrangement was made with Cammell for them to roll Brown's armour output should the armour mill be occupied for shell steel.[29] Overall Brown's armour mill produced 18,381 tons of shell bars between May 1916 and June 1917, after which the mill was converted back to armour production.[30] With shell steel still in demand, a second conversion was agreed in November 1917 and completed six months later.[31] Production restarted in July 1918 for six months, producing a further 4,034 tons of shell bars, after which the plant was converted permanently to its original purpose.[32] The record of Brown's expansion during the war highlights that, despite being predominantly used for the production of armour, some of the plant installed at armourers' works could be utilised for other armaments output. However, the vast demands for shell steel were unique to wartime production as in peacetime the projectile manufacturers were able to supply all the steel required from their own works.

As has been demonstrated, in addition to extending their own manufacturing capabilities and exploring new product areas, the Sheffield armaments manufacturers utilised a network of facilities in order to fully exploit their productive capabilities. This collusive action was a defensive manoeuvre in order to avoid new entrants to the industry, and blurred the boundaries between those involved.[33] With the small number of companies in the Sheffield armaments industry, it can be described as a 'capsule' network, one which is 'relatively small in membership, self-contained and impermeable.'[34] The sharing of technological knowledge among the Sheffield armourers in the years prior to the Great War created a high-trust network through the licensing and business connections developed. Popp and Wilson have suggested that such high-trust

[28] SA. X308/1/2/1/3/12, Brown's Managing Directors Report, 3 August 1916.
[29] SA. X308/1/2/1/3/12, Brown's Managing Directors Report, 3 August 1916.
[30] SA, X308/1/4/1/2/1 to 2, Brown's Works Committee Agendas and Papers, 1916 to 1917.
[31] SA, X308/1/2/1/3/13, Brown's Managing Directors Report, 29 November 1917.
[32] SA, X308/1/4/1/2/2 to 3, Brown's Works Committee Agendas and Papers, 1917 to 1918.
[33] On the boundaries of the firm, see G. Boyce and S. Ville, *The Making of Modern Business*, (Basingstoke, Palgrave, 2002), 24-27.
[34] A. Popp, S. Toms, and J. F. Wilson, 'Industrial Districts as Organisational Environments: Resources, Networks and Structures', *Management and Organisational History*, Vol.4, No.1. (2006), p.363.

networking ‘could shade into collusive behaviours.’[35] While this was the case from the examples presented, the armament companies were also involved in expanding the capabilities for munitions production with other companies in Sheffield and further afield.

In May 1915 the Ministry of Munitions was created and with it the establishment of local munitions committees. Consequently the Sheffield Committee on Munitions of War (SCMW) was formed which sought the armaments companies’ advice on which of their sub-contractors they could approach to expand the local production of shells.[36] Sub-contracting was common in the armaments industry and by the end of 1914 Cammell had entrusted the Sheffield Simplex Motor Works with the production of finished 12 and 14 pound shell, and 2.75 inch shrapnel shell.[37] The order was placed with the company in September 1914, with the first deliveries expected at the end of the month. When no deliveries were made by November, the experiment was deemed a failure and the shells were finished at Cammell’s own works.[38] By July 1915, for shell work Firth were sub-contracting with three companies for steel, two for punching and drawing steel, 17 for machining, eight for copper bands and tubes, five for nose bushes, and 13 for shrapnel components.[39] After an initial meeting between the SCMW and representatives of Brown, Cammell, Firth, Hadfields and Vickers in June 1915, by July the armourers were looking to protect their own interests and refused to divulge any information. Augustus Clerke, representing Hadfields at the meeting, suggested that ‘the practical demonstration of the manufacture of shells and the rapid training of unskilled labour to be drafted into the shops of the armament firms’ was the best course of action.[40] The two sides had reached an impasse, the armourers looking to protect their interests and keep their technical information secret, and the SCMW not willing to be subservient to the established companies. After further

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[35] A. Popp, and J.F. Wilson, 'Districts, Networks and Clusters in England: An Introduction' in A. Popp, and J.F. Wilson (Eds) *Industrial Clusters and Regional Business Networks in England 1750-1970,* (Aldershot, Ashgate, 2003), p.15.
[36] For a general overview of the work of the SCMW, see the *Official History of the Ministry of Munitions,* Volume II/2, Part 2, pp.89-91.
[37] Wirral Archives (WA), ZCL/5/56, Cammell Laird Report of Sheffield Financial Results 1914, p.151.
[38] *Official History of the Ministry of Munitions, Volume 1: Industrial Mobilisation 1914-15*, Part 1: Munitions Supply 1914-15, Chapter IV, pp.127-8.
[39] *Official History of the Ministry of Munitions, Volume 1: Industrial Mobilisation 1914-15*, Part 1: Munitions Supply 1914-15, Chapter IV, pp.104.
[40] Sheffield University Library Special Collections (SULSC), MS 76/B8, SCMW Management Committee (sub-committee) minutes, 2 July 1915.

negotiations, training was ultimately provided by the armourers to assist firms who had not previously manufactured shell. At Cammell, their training scheme was focused on providing guidance and instruction to their own sub-contractors who had not produced shell before.[41] Hadfields were involved with the training of a large number of companies in the production of high explosive shell, and by March 1918 the list included 58 'competitive engineering firms', of which 9 were in Sheffield, and included Somers Co and the Darlington Forge Co which received Brown's shell bars; 6 'projectile manufacturers' in Beardmore, Cammell, Firth, Harper Bean and Co of Dudley, and Vickers at Barrow and Sheffield; 13 corporation munitions committees, including the one established in Sheffield; 13 national projectile factories; and a further 7 companies and departments in the US, France, Russia and Australia.[42] Robert Abbott Hadfield was keen to demonstrate how his company was assisting the war effort, and in October 1915 wrote to the Ministry of Munitions about their training program:

> Vickers consider they know a good deal about armaments production, but they came down specially to see our works and methods, and are, we understand, adopting our ideas. Sir Vincent Calliard [of Vickers] himself saw and wrote me, and although in ordinary times we should not of course have agreed to show our improvements to competitors, in this time of war and stress we are only too glad to do anything we can to help the nation.[43]

The sharing of Hadfields' 'improvements' continued throughout the War. In early 1915 Hadfield with A.G.M. Jack introduced their 'Patent Blank' method of shell production. This was a relatively simple process and involved the casting of a shell 'blank' into an ingot, before being pressed to shape ready for machining into a finished shell. By producing shells in this way, any need for hammering, rolling or forging was eliminated, avoiding unnecessary and time consuming additional stages in shell production. In wartime, projectile companies were looking for any means of simplifying the manufacture of shell to keep up with demand. Hadfields used this method of production for high explosive shells from 6 to 15 inch in size, and claimed to have obtained a saving for the Government of around £400,000 by installing the method of production at

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41 'The History of Cammell Laird' in *Sun and Agricultural Journal of South Africa,* January 1920, p.43.
42 SA, Hadfields Box 56, Statement of Great War Armaments Tuition at Hadfields, 1918.
43 TNA, MUN 4/83, Sir Robert Abbott Hadfield to Sir Frederick Black, 8 October 1915.

Hadfields and their National Projectile Factory in Tinsley.[44] The patent and method were also licensed, free of charge, to the Ministry of Munitions in 1916, with the Ministry commending the 'patriotic spirit' in which the offer was made.[45]

As part of their training program, Hadfields also taught Beardmore of Glasgow, Taylor Brothers and Co of Manchester, and Vickers in Sheffield and Barrow on casting blanks, in addition to Schneider in France and Tochinesky of Russia.[46] Hadfield also refined the process of producing high explosive shells with a new heat treatment and the addition of 2% nickel and 2% chromium to the steel to be used.[47] This was the same composition used in the production of the original Heclon AP projectile in 1904, and demonstrates how the metallurgical techniques developed at Hadfields could be adapted for new purposes. When Hadfields' National Projectile Factory ceased production of shells in early 1918 and moved onto the repair and manufacture of howitzer guns, the patent blank method was modified to produce gun barrels, again without the need for hammering, rolling or forging. The patent for the new gun manufacture technique suggested that the method '…enabled engineering works unprovided [sic] with plant of the kind referred to, to be quickly adapted for the manufacture of such gun tubes, features of great practical and national importance *under present war conditions*.'[48] Through their training program, Patent Blank innovation and further developments with high explosive shell and gun barrels, Hadfield was effectively protecting his company's investment in armaments technology from before and during the War. Furthermore, their provision of training to other companies provided Hadfield with a means of emphasising and controlling their contribution to the War effort. Much like the use of the 'Hadfield System' of AP projectile production before the Great War, training provided Hadfields with a means of controlling their knowledge leaving the firm, and principally stifling the possibility of a new competitor entering the market. The Great War showed above all else that the production of high explosive shell extended to a wider range of companies than just the armaments manufacturers, while the production of armour piercing projectiles

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[44] SA, Hadfields Box 59, Hadfields Patents and Royalties Statement 1918, p.5. See also British Patent 4228/1915.
[45] SA, Hadfields Box 55, Ministry of Munitions to Sir Robert Abbott Hadfield, 8 August 1916.
[46] SA, Hadfields Box 56, Statement of Great War Armaments Tuition at Hadfields, 1918.
[47] British Patent 128,961/1916, p.3.
[48] British Patent 142,146/1918, pp.5-6. On Hadfields' National Projectile Factory, see *The Official History of the Ministry of Munitions Volume VIII: Control of Industrial Capacity and Equipment*, Part 2, The National Factories, p.147.

remained 'one of the most exacting and difficult metallurgical feats.'[49] Hadfields, along with Firth, Cammell and Brown, all positioned themselves to remain key elements of the British armaments industry for supply to the Admiralty once peace arrived. They were keenly aware of the need to position themselves to meet the challenges of the post-War competitive environment.

Hadfield's metallurgical knowledge influenced other aspects of innovation at the company during the Great War. Use was found for Hadfield's 'Era' manganese steel in helmets and body armour for soldiers. Spurred on by the use of his material, Hadfield turned his inventive mind to refining their designs. His first development involved creating an improved means of adjusting the fitting of the helmet for the wearer.[50] The second involved an improved means of manufacturing manganese steel sheets for conversion into helmets or body armour, and involved casting the material into 'perfectly sound ingots.'[51] From 1916 to August 1918, Hadfields produced over 1,500 tons of 'Era' Manganese steel for helmets and body armour.[52] The use of steel helmets was a 'retro-innovation', an older piece of protection from the history of warfare updated for the modern soldier, though 'a process of innovation was also occurring in terms of how it was manufactured and in its physical and chemical make-up' to make it appropriate to warfare on the Western Front.[53] Innovation also occurred with other armaments technology at the company. In 1917 Hadfield experimented with the use of armour piercing projectile technology with the manufacture of bullets,[54] and also explored the production of bullet proof steel, using an alloy composed of 0.7 to 2% silicon, 1.5 to 3% chromium and 2.5 to 5.5% nickel. Utilising the metallurgical knowledge created during the previous decade, Hadfield claimed that the material could withstand armour piercing projectiles and bullets.[55] Elsewhere, other armament companies were utilising their prior research and knowledge to respond to the practical issues of using their

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[49] TNA, T181/69, Royal Commission on the Private Manufacture of and Trading in Arms, Hadfields Evidence, 16 October 1935.
[50] British Patent 105,348/1916.
[51] British Patent 133,131/1917, p.1.
[52] SA, Hadfields Box 113, Statement on Output of Special Products, 26 September 1918. On manganese steel helmets, see also R.A. Hadfield, *Metallurgy and its Influence on Modern Progress* (London, Chapman and Hall, 1925), pp.100-101.
[53] F. Guelton, 'Technology and Armaments' in J. Winter, *The Cambridge History of the First World War: Volume 2, The State* (Cambridge, Cambridge University Press, 2014), p.244. In his discussion of the steel helmet's development, Guelton makes no mention of Hadfield or manganese steel.
[54] British Patent 120,774/1917, 127,851/1917.
[55] British Patent 126,049/1916.

products in wartime. At Firth the research team of James Rossiter Hoyle and Harry Bland Strang (who reverted from Strange to the traditional Scottish spelling of his surname during the War) continued to explore the development of specialised projectile fuzes. In 1916 they patented two new designs, one capable of detonation after hitting the fabric of an aeroplane or water, an updated design based on their previous work.[56] The development of these two fuzes was directly related to feedback from the experiences of soldiers using them, and older designs were not working as efficiently as expected. Another new area of manufacture from 1915 was material for the production of tanks. In Sheffield, Vickers, Cammell and Edgar Allen were all involved with the manufacture of tank armour, and Hadfields supplied caterpillar tracks for the new fighting machines.[57]

Armour technology was also advanced during the War, and Captain Tolmie John Tresidder at Brown produced an updated treatment for carburising the face of an armour plate in order to avoid altering the composition of the steel.[58] In 1916 at Brown vanadium was introduced into alloy steels for shield roof plates, and remained in use for armour production at the company into the 1920s.[59] However, it was in the continued development of practical solutions to defeat capped AP projectiles which Tresidder had his greatest success. Tresidder was well aware that even by 1917 guns still held a 'superiority of attack over defence.' The inability of armour to withstand the impact of shell was 'largely due to the protection conferred upon the point of the shell by the cap attached to it for that purpose, and all attempts hitherto made to cause the cap to function prematurely by placing plates, or the like, in front of the armour have failed.'[60]

Building on his previous work in this area, Tresidder developed a 'Decapping Device' which involved building a mesh net consisting of wire, rods or strips over a ship's armour to prevent the cap of an AP projectile enabling the perforation of the armour plate (See Figure 5.1).[61] A second design was also

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[56] British Patent 124,826/1916, 126,048/1916.
[57] J. Singleton, 'The Tank Producers: British Mechanical Engineering in the Great War', *Journal of Industrial History,* Vol.1, No.1 (1998), pp.92-3.
[58] British Patent 3,423/1915.
[59] SA, X308/1/2/1/3/12, Brown's Managing Directors Report 30 August 1916.
[60] British Patent 127,660/1917, pp.1-2.
[61] British Patent 127,660/1917, p.2.

introduced to protect the roofs of gun turrets on ships from attack.[62] Tresidder's Decapping Device entered production in mid-1918 after successful trials and an order for the device to be fitted to all of the Royal Navy Grand Fleet's capital ships was recorded from the Admiralty.[63] Manufacture took place in Sheffield at Brown's Atlas Works, while the device was fitted to ships docked for overhaul at the Coventry Ordnance Works' Scotstoun Works in Glasgow.[64] Such was the urgent requirement from the British Admiralty for Decapping Devices, and with a shortage of labour at Brown, their managing director William Ellis approached James McNeill Allan of Cammell for the assistance of 'a few gangs of fitters' to assist, which Allan was 'pleased to supply.'[65] The production of the Decapping Device once again demonstrates the collaborative nature of armaments companies' relationships during the War, as each was open to assisting their fellow armaments companies when required. In all of these cases innovation occurred in response to practical wartime use of the armaments companies products. These designs and improvements were built on knowledge and research developed prior to the war, and in each case demonstrates the path-dependent evolution of armaments, using incremental improvements and sub-innovations to refine their performance.[66]

During the Great War the armaments companies sought to protect their own interests and capabilities in a collusive manner. Through three main areas of development, expanding their capabilities and the establishment of a productive network, collaboration and education of other companies and through experimentation and innovation they acted in a defensive manner and sought to maintain their position as the key armaments companies in Britain once the war was over. This was predominantly facilitated by building on the links the company's had built up in the decade before the War began. However, in one area more innovation and collaboration took place; the development of armour piercing projectiles for oblique attack.

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62 British Patent 129,367/1917.
63 Sheffield City Library (SCL), *General Description of the Works and Products of John Brown and Company Ltd*, 1924, p.27.
64 SA, X308/1/2/1/3/14, Brown's Managing Directors Report, 25 June 1918.
65 SA, X308/1/4/1/1/2, Brown's Works Committee Meeting Minutes, 30 July 1918.
66 See N. Rosenberg, *Exploring The Black Box* (Cambridge, Cambridge University Press, 1994), Chapter 1: 'Path-dependent aspects of technological change.'

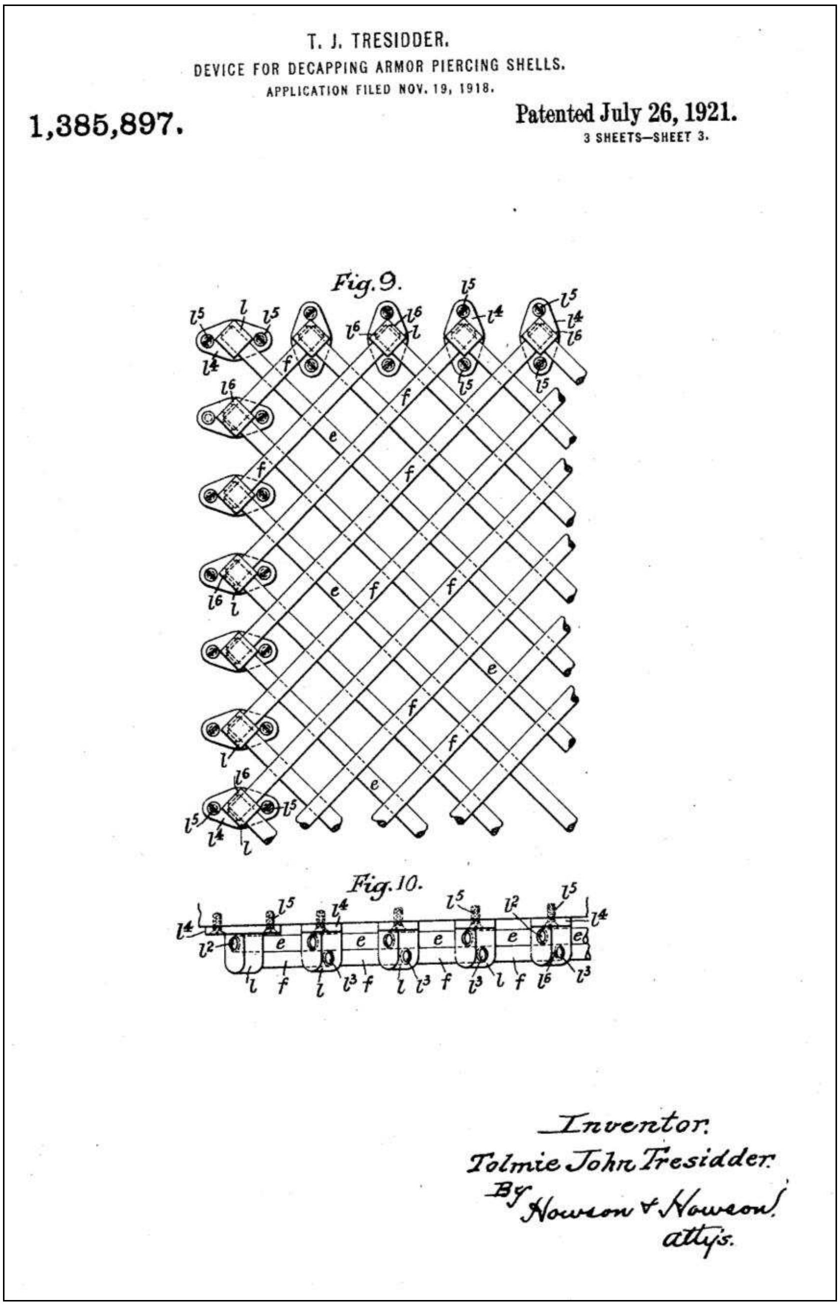

Figure 5.1: Example of Tresidder's Decapping Device, taken from US Patent 1,385,987, identical to the British Patent.

The Lessons of Jutland: Armour Piercing Projectile Developments 1916-1930

The Battle of Jutland, from 31 May to 1 June 1916, was the largest encounter between surface ships of modern times.[67] The Royal Navy's Grand Fleet, under the command of Sir John Jellicoe and Sir David Beatty, had 151 ships at its disposal, including 28 dreadnoughts and nine battle cruisers. In contrast, the German High Seas Fleet, commanded by Reinhard Scheer and Franz Hipper,

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[67] P. G. Halpern, *A Naval History of World War I* (London, UCL Press, 1994), p.316,

had a total of 99 ships at sea, including 16 dreadnoughts, five battle cruisers, and six pre-dreadnought battleships. As submarines played no part in the battle, and aircraft only a marginal role, it was principally a one-dimensional combat between a combined fleet of 250 surface ships in the North Sea near the Jutland peninsular.[68] After an initial encounter between the battle cruisers of Beatty and a scouting force under the command of Hipper on the afternoon of 31 May 1916, the full fleet action began in the early evening. After two major encounters between the capital ships of Jellicoe and Scheer, the fighting continued into the night. By sunrise on 1 June 1916, Scheer and his High Seas Fleet had withdrawn to German waters, bringing the battle to an end.[69] In total, the Grand Fleet lost fourteen ships, including three battle cruisers, along with 6,768 men killed or wounded. The German High Seas Fleet fared better, loosing eleven ships, including one battle cruiser and one pre-dreadnought battleship, with 3,058 men killed or wounded. While Scheer and the contemporary German press presented the battle as a victory based solely on the number of ships sunk and seamen killed or wounded, Massie has suggested that superiority remained with the British based on the number of ships available after the battle.[70] Regardless of outcome, the Battle of Jutland highlighted some serious technological flaws with British armour piercing projectiles.[71] In battle conditions where the angle of impact between the projectile and armour varied greatly from the 'normal' line of attack (a right angle to the plate), many of the projectiles fired failed to perforate the armour and detonate inside the ship they were launched against.

The Great War was a laboratory for experimentation in the art of modern industrial warfare, and at Jutland it brought home to the Admiralty the deficiency in the capability of projectile attack to overcome armour defence. Yet prior to the war, at both Hadfields and Firth, the problem of oblique attack had been known and largely overcome. Both companies had patented cap designs for oblique attack and sold projectiles fitted with the updated caps to foreign governments.

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[68] Halpern, *Naval History*, p.316,

[69] There is a rich literature on the history of the Battle of Jutland, see for instance, A. J. Marder, *From the Dreadnought to Scapa Flow, Volume 3: Jutland and After* (Oxford, Oxford University Press, 1966); A. Gordon, *The Rules of the Game: Jutland and British Naval Command* (London, John Murray (Publishers), 1996); and R. K. Massie, *Castles of Steel* (New York, Random House, 1993), Chapters 31 to 34.

[70] Massie, *Castles,* p.665.

[71] Marder, *Dreadnought,* pp.169-171; Massie, *Castles,* pp.667-668; Halpern, *Naval History,* p.328.

Seven years before Jutland, in 1909 Firth had supplied the Russian Government with projectiles capable of an attack at 20 degrees to the normal, and had sold to the Italian Government in 1915 their latest shell caps for oblique attack.[72] Hadfields' projectiles supplied to the US Navy in 1909 and 1912 were also tested for attack at 10 degrees to the normal.[73] As Brasseys Naval Annual recounted after the War:

> In following the developments of the soft-steel [pre-War] cap, it must always be remembered that the British proof conditions called for the attack of plates at the normal, with the natural result that both shell and cap gradually became specialised instruments for this purpose, and little to no encouragement was given to manufacturers [by the Admiralty] to progress in knowledge of oblique attack.[74]

Jutland was a hard learning curve for the Admiralty, and new AP projectiles which could perforate armour at oblique angles were requested soon after. For this they were reliant on Hadfields and Firth, undoubtedly two of the most advanced projectile manufacturers in the world at the time, to assist in their development.

The initial focus of research at both companies was to redesign the cap and head of the projectile, switching from soft to hardened steel and drawing on their metallurgical knowledge. Robert Abbott Hadfield's first attempt at a refined cap in late 1916 utilised a 4% nickel and 2% chromium steel with a new treatment process.[75] Firth's research team of Harry Bland Strang and James Rossiter Hoyle began exploring new head designs for armour piercing projectiles in July 1917, with a design incorporating a head more adept at biting into the surface of an armour plate at oblique angles. The patent also referred to utilising Firth's pre-War cap designs in conjunction with the improvement.[76] In each case, the two companies looked to further develop and improve the projectile designs they had been using for over a decade with new sub-innovations, though progress was slow and working alone did not produce adequate results. Closer collaboration between the two companies was

[72] TNA, T181/68, Royal Commission on the Private Manufacture of and Trading in Arms, Firth-Brown Evidence, 2 October 1935; Brasseys Naval Annual 1924 Extract, 'The Evolution of the Modern AP Projectile', p.8.
[73] SCL, *The Evolution of the Modern AP Projectile,* 1924, p.9.
[74] SCL, *The Evolution of the Modern AP Projectile,* 1924, p.8.
[75] British Patent 127,601/1916, p.3.
[76] British Patent 125,671/1917.

suggested, and in September 1917 Hadfields and Firth signed a new agreement for the sharing of technological information and resources. The arrangement was for a 'mutual interchange' regarding shells and projectiles 'of knowledge between the technical officials of the respective staffs [and] the joint use of certain of each others shell patents.' Firth also gained access to Hadfield's testing range at the East Hecla Works.[77] Terminable on six months notice from either side, the agreement was set to last until the end of the War, but remained in force until the 1930s. The purpose of the arrangement was collusive; by pooling their resources the two companies could potentially find a solution to oblique attack sooner than working in isolation. Commenting on a similar arrangement between Vickers and Armstrong in 1902 over the sharing of knowledge relating to gun mountings, Singleton has suggested that the two created a 'duopoly in technical competence.'[78] With their agreement, Hadfields and Firth created a duopoly of *projectile* technical competence. As a consequence of the new agreement, in 1918 Firth updated their arrangement with Harry Bland Strang to pay him 25 per cent of all funds received from Hadfields for the use of their patents.[79] The management of Firth was clearly aware of the importance of Strang to the advancement of the company's technological reputation, and chose to continually reward him for his contribution.

Research continued unabated at the two companies into various new designs. Hadfield and Alexander Jack in 1918 designed a cap with a series of sharp indentations on the surface to bite into the armour.[80] At Firth, Strang and Hoyle patented two designs which separated the head of the projectile from the rest of the body, with the head held in place with one of Firth's previous cap designs.[81] A similar 'divided head' design was also developed at Hadfields.[82] The sharing of experimental data and collaboration between the two companies resulted in a jointly patented cap design, nine months after the signing of their

[77] SA, X306/1/2/3/1/5, Firth's Directors Meeting Minute Book No.5., 25 September 1917, p.5; SA, Hadfields Box 67, Hadfields-Firth Shell Agreement, 4 September 1917.
[78] J. Singleton, 'Full Steam Ahead? The British Arms Industry and the Market for Warships, 1850-1914' in J. Brown and M.B. Rose, *Entrepreneurship, Networks and Modern Business* (Manchester, Manchester University Press, 1993), p.247.
[79] SA, X306/2/3/2/3, Arrangement Between Firths and Harry Bland Strang, 1918.
[80] British Patent 130,692/1918.
[81] British Patent 125,737/1918, 125,738/1918.
[82] British Patent 142,145/1918, p.4.

September 1917 agreement.[83] It was the only patent ever to be issues jointly by two Sheffield armament companies. The cap design utilised an alloy comprised of 2-4% nickel and 1.5-3% chromium, treated to provide a hardened point and successively softer layers behind it. This ‘hardened cap’ design was a departure from the pre-War ‘soft cap’ designs used for the Heclon and Rendable AP projectiles. In the specification the only suggestion for the shape of the cap was that they ‘have a rounded or blunt end portion or head capable of striking a hard faced armour plate over a small localised area.’[84] From here the two company’s designs for AP projectile caps diverged, as Firth would design a blunted cap, known as the ‘Knob Cap’, while Hadfields continued with a ‘Rounded Cap’ design.

Developed alongside these new designs was an updated treatment processes for the body of the projectile. In early tests, new caps fitted to old projectile bodies proved ineffective, as during oblique perforation the body of the projectile was subjected to stresses unknown during normal attack conditions which could cause the projectile to crack and fail to detonate.[85] Research into updating the treatment of the body of the projectile had begun in 1915 at Hadfields, with a method of creating a hardened head portion of the projectile, and a progressively softer body.[86] This method of treatment continued to be researched, and in 1916 a means of toughening the hardened projectiles had been devised.[87] In steel production, hardening refers to treating steel to increase the amount of force which can be exerted upon it, or in the case of projectiles it upon armour, without causing the material to distort or fracture. Toughness is the amount of strain or force which can be exerted upon the material without causing cracks or breakage. With projectiles this invention countered the stresses experienced while perforating armour. A final revision of the hardening process further treated the projectile head to aid in oblique perforation and ‘bite’ into the surface of the armour.[88] Also developed was an extrusion process for shaping the walls and cavity of the shell, derived from

[83] British Patent 142,149/1918.The names cited on the patent from Hadfields were Robert Abbott Hadfield, Alexander George McKenzie Jack, and Isaac Bernard Milne. From Firth were James Rossiter Hoyle, Harry Bland Strang and Esmond Morse.
[84] British Patent 142,149/1918, p.4.
[85] SCL, *The Evolution of the Modern AP Projectile,* 1924, pp.9-10.
[86] British Patent 6993/1915.
[87] British Patent 127,602/1916, p.3. The patent refers to the heat treatment by citing British Patent 6993/1915.
[88] British Patent 142,143/1918, p.6.

Hadfield's work with 'Patent Banks' discussed above.[89] Though these developments were solely the work of Hadfields, the 1917 agreement meant these production methods had to be shared with Firth. As a result, by February 1918 Firth were operating a shell hardening and tempering plant identical to the one at Hadfields.[90] Firth benefited from the arrangement with Hadfields far more than their research partner, as more technical knowledge and patent rights passed from their collaborator than they returned.

The result of these developments was a projectile which could perforate armour at oblique angles. This swift development was followed by rapid production and delivery to the Navy. In early 1917 the Admiralty had ordered all older defective shell off ships, yet it was not until April 1918 that sufficient numbers of new projectiles began to arrive. Jellicoe claimed that their design 'certainly doubled' the offensive power of the Navy's heavy guns. By the end of the Great War 12,000 new armour piercing projectiles of 12 inch calibre and above had been delivered, though none of them would be fired in wartime.[91] The new projectiles were based on a series of sub-innovations to solve the problem of oblique attack, continuing the path-dependent research at both Hadfields and Firth.

After the Armistice in November 1918 developments with AP projectiles continued in Sheffield, as Hadfields and Firth experimented with updating the shape of the head of their projectile designs to aid in oblique attack, using a measurement derived from the calibre of the shell.[92] Hadfields also updated their Rounded Cap design to increase their size from 75 percent to 98 percent of the calibre of the projectile, as testing had revealed this would aid oblique perforation.[93] In each case the refinements were related to the optimum size and shape of the projectile, rather than metallurgical composition and treatment. This suggests that, as had been the case with armour, practical updates and observations were required for future development. Elsewhere Cammell, who

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[89] British Patent 142,148/1918.
[90] SA, X306/1/2/3/2/169, Firth's Directors Meeting Agendas and Papers 26 February 1918; SA, Hadfields Box 64, Robert Abbott Hadfield to Major A.B.H. Clerke, 18 February 1924.
[91] Marder, *Dreadnought,* p.216.
[92] SA, X306/1/2/3/2/184, Firth's Board Meeting Agendas and Papers 29 April 1919, SA, Hadfields Box 53, Draft memorandum on the history of armour piercing projectiles, 16 January 1934. This design utilised a calibre radius head measurement, which is a curve derived from the size of projectile with which it would be utilised. Experiments at Hadfields explored a 1.64 calibre radius head, Firth a 1.6 calibre radius head, before both settled on a 1.4 calibre radius head.
[93] British Patent 164,056/ 1919, p.3.

where not involved in any AP projectile developments, continued producing and testing their 'Allan' cap into 1918, and continued to manufacture Firth's Hollow Caps.[94] In 1920, production of all projectiles ceased at Cammell, their shell shops thereafter converted for the production of light forgings.[95] Vickers also ceased shell production, suggesting that the ease with which civilian producers could commence manufacture meant their production was 'inappropriate for a thoroughbred armaments firm.'[96] By 1920, Firth and Hadfields were the only remaining private producers of projectiles in Sheffield. The role of armaments companies as suppliers may have become defunct by the end of 1918 due to the changing international environment, yet their role as designers of weapons continued.[97]

In the 1920s research at the two companies focused on refining the base of the projectile. When perforating armour at an oblique angle, the base was liable to break, in some cases fracturing the charge chamber and preventing detonation. Hadfields' first design, an 'Annular Base Groove' was patented in 1922.[98] Though initially successful with 20 degree attack, the design proved ineffective once the testing for oblique attack increased to 30 degrees. A new design was developed by Hadfield and Augustus Clerke in 1930 which mounted the charge chamber further into the projectile than previous specifications, leaving a hollow area in the bottom of the projectile. This was where cracking due to oblique attack occurred, without damaging the charge and allowed successful detonation.[99] Patented as the Hadfield-Clerke 'Relief Base', the design would remain in use until after the Second World War as standard for all AP projectiles (see the example in Figure 5.2).[100] Firth's projectile developments also refined the base of the projectile, though the company were blocked from taking out a patent for a shell adaptor in 1927, a consequence of a new agreement with the Admiralty with strict secrecy stipulations.[101] It is likely this was not an isolated case, and far more research could have taken place in the

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[94] WA, ZCL/5/43. Cammell Laird Board Meeting Minute Book No.10, 8 May 1918, p.417.
[95] SA, ESC Box 192, Cammell Laird Sheffield plant sales and details, 1910-1927.
[96] G.A.H. Gordon, *British Seapower and Procurement Between The Wars: A Reappraisal of Rearmament* (Annapolis, Naval Institute Press, 1988), p.87.
[97] R.P.T. Davenport-Hines, *The British Armaments Industry during Disarmament* (Unpublished Thesis, University of Cambridge, 1979), p.18.
[98] British Patent 202,681/1922.
[99] British Patent 353,425/1930.
[100] *The Engineer*, 20 May 1949, p.559.
[101] SA, X306/1/2/3/1/5, Firth's Directors Meeting Minute Book No.6, 25 October 1927, p.186.

1920s with projectile designs than is reflected in the patent record. With experimental and testing reports no longer in existence, if they were recorded at all, it is impossible to know for sure. When two patents appeared from Strang and Firth in 1929, it was their first related to armaments developments since 1918, and were entirely dedicated to practical solutions to prevent the base of the projectile breaking during oblique perforation.[102] During the 1920s, research and development at both companies took place against a backdrop of declining demand for projectiles from the British Government. Much like the technological activities of the Sheffield armourers in the Great War, their dedication to continuing to develop projectile sub-innovations must be seen as a defensive decision in order to maintain their position as technologically advanced producers. They needed to be prepared with the most advanced projectile design should demand return in the future, as it did in the mid 1930s.

By 1930, the AP projectile designs of the two companies represented over three decades of dedication to continued technological development and refinement. Beginning with two major innovations, cast steel for projectiles at Hadfields, forged steel at Firth, both companies developed numerous sub-innovations which progressively advanced and refined the performance of their projectiles, building two distinct, path-dependent bodies of research. Their designs and approaches varied, Firth utilising more practical solutions and designs in contrast to the predominantly metallurgical solutions favoured by Hadfields. In this regard, Robert Abbott Hadfield's work with armour piercing projectiles reflects a life's dedication to their improvement. He consistently adapted and developed a design based on a major innovation in response to changing Government requirement, drawing extensively from his metallurgical knowledge and utilising fellow board member's experience when required. While Hadfield is rightly remembered as a genius of the Sheffield steel industry, his work with projectiles is predominantly overlooked.[103] In this field, though an adjunct of his metallurgical research, he should equally be regarded as a genius.

[102] British Patent 329,966/1929, 329,967/1929.
[103] G. Tweedale, *Steel City, Entrepreneurship, Strategy and Technology in Sheffield 1743-1993* (Oxford, Clarendon Press, 1995), p.54.

Figure 5.2: Hadfields' Advert from 1934, showing the relief base design. Taken from 'Note on the New Armour Piercing Projectile', reprinted from Brassey's Naval and Shipping Annual 1934.

Overall, the development of AP projectiles during and after the Great War highlights that the application of metallurgical knowledge ceased to provide any further improvements after 1918. Solely practical solutions were required to refine the performance of projectiles, and in turn no information would be provided for exploitation in civilian metallurgical developments. Nevertheless, for around two decades from the late 1890s to 1918, armaments technology and metallurgy developed and matured in tandem; armaments an industry which had the potential to benefit from alloy steel development, treatment and production techniques, metallurgy in need of an industry where systematic research and development would serve to advance the field beyond the activities of enthusiastic individuals such as Hadfield. At the end of the Great War, the potential for utilising alloy steels in a wide range of applications had been realised. For the civilian metallurgist after the War, the spin-off from the development of armaments was a vast knowledge base of research into the application of various elements to alloy steels, treatments and productive techniques. As the two industries research trajectories began to take different paths, the metallurgical information available was ripe for exploitation.

Armaments and Metallurgical Developments 1914-30

In 1914 it was acknowledged that some of the finest achievements in metallurgy in the 50 years prior had been initiated by the development of the battleship.[104] This was reiterated in 1925 when Hadfield discussed the development of alloy steels in his book *Metallurgy and its Influence on Modern Progress*:

> Just as modern civilisation could not be carried on without the use of alloy steels, so warfare could not be conducted without them in the scientific manner and on the gigantic scale with which we are unhappily too familiar. War, with all its attendant horrors, is not to be counted amongst the blessings of civilisation; but in this instance, at any rate, some good has been derived from evil, because the development of alloy steels for the purposes of peace has been largely assisted by their application to war material.[105]

The work of the Sheffield armaments industry stood at the centre of this advance, their work on armour and AP projectiles contributing exponentially to the pool of information developed on the effect of various elements in alloy steels, treatments and production techniques available to the industry. As Sayers has suggested, ‘it is difficult to overestimate the importance, to the whole metallurgical field, of the work done by a handful of men in the private research establishments of the Sheffield steelmakers.’[106] Tweedale has also suggested that ‘the First World War saw no interruption in the development of the practical application of scientific techniques. Indeed, it accelerated it. Not coincidentally, many of the most scientifically advanced steelmaking firms, both

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[104] Trebilcock, Spin-off, p.482.
[105] Hadfield, p.175.
[106] R.S. Sayers, ‘The Springs of Technical Progress in Britain 1919-39’, *The Economic Journal*, Vol.60, No.238 (1950), p.282.

in Sheffield and abroad, were armaments producers.'[107] Advances in the application of science, the erosion of rule of thumb methods, and the expanding use of alloy steels in the Sheffield steel industry was principally advanced by private armaments companies, most of whom were not averse to reminding the world of their contributions, their annual meetings used for social reporting. Brown's chairman Baron Aberconway said in 1915 that if anyone examined 'the development of all naval and military appliances during the last 50 years they would find that a large proportion had been due to the skill and enterprise and the inventive capacity of private firms,' before highlighting that:

> Developments and improvements in high-class steel, in armour-plate, and in marine engineering in all its branches…were nearly all based on metallurgical discoveries, and the patient investigation and experiment by which the country benefited had been carried on at the expense of such firms and their shareholders.[108]

Robert Abbott Hadfield, never one to play down his own or his company's achievements, gleefully told his shareholders in 1915 that 'important developments which have originated from Hadfields [are] a result of careful and painstaking research, and for which world-recognition has been credited to us…Remember, my firm does not copy, we *originate,* and lead the way.'[109] Hadfield also suggested that, 'in the metallurgy of iron and steel Sheffield has not the slightest reason to feel she is in any other position than that of leading the world in the development of special steels of the highest quality.'[110] This lead in special steel development was enabled by armaments research prior to the Great War, but was then utilised in the context of an industrial war. These developments were part of a long-established continuum between armaments-based and commercial-based metallurgical developments in Sheffield, the two areas consistently influencing developments in each other.

The pool of metallurgical knowledge spun-off from armaments technological developments included the use of manganese, nickel, chromium, tungsten, molybdenum, boron, vanadium, and tantalum, and their effect on the performance of alloy steels. This knowledge was utilised by the companies

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[107] G. Tweedale, 'Science, Innovation and the 'Rule of Thumb': The Development of British Metallurgy to 1945' in J. Liebenau (Eds.), *The Challenge of New Technology – Innovation in British Business Since 1850* (Aldershot, Gower, 1988), p.73.
[108] *The Times*, 30 June 1915.
[109] SA, Hadfields Box 9, Hadfields AGM Report 1915, p.8. Emphasis in original.
[110] SA, Hadfields Box 9, Hadfields AGM Report 1915, p.9.

which were part of the armaments-metallurgical-steel innovation system which emerged with its centre in Sheffield prior to the Great War.[111] Furthermore, though impossible to substantiate, some metallurgical knowledge derived from armaments undoubtedly spread to the wider Sheffield steel industry, communicated through informal networks of metallurgists and professionals with links to educational institutions, the University and other social groupings. Building on this pool of knowledge, in Sheffield from 1914 the main areas of research and development in metallurgy were with heat and stain resisting steels. The key elements used in these materials were nickel and chromium, not coincidentally the main elements used in Krupp Cemented armour and AP projectiles produced by the Sheffield armaments industry. Adding other elements to what are known as 'nickel-chromium class' steels was the basis of all the knowledge spun-off from armaments developments, and at the core of developing new specialist steels. The use of nickel-chromium steels can be seen as a type of common knowledge to the companies in the armaments-metallurgy-steel innovation system, subsequently increasing their capacity to absorb new knowledge related to future developments with versions of the material and increasing the likelihood of new metallurgical knowledge to be transferred between them.[112] No where was this more apparent than in the development of stain resisting steels.

Following Harry Brearley's successful discovery and development of stainless steel, Firth received their first orders for the material in February 1915.[113] The same year, Brown, Hadfields, Vickers, Brown Bayley and Sanderson Brothers all commenced stainless steel manufacture, all similar in composition to that discovered by Brearley in the Sheffield area, making patenting the material in Britain impossible.[114] Brearley subsequently patented stainless steel in the US, the patent application helped by the advice of Robert Abbott Hadfield who had a 'near-miss' with the material when experimenting

[111] For the emergence of this system, see Chapter 2.
[112] S. Pinch, N. Henry, M. Jenkins and S. Tallman, 'From 'Industrial Districts' to 'Knowledge Clusters': A Model of Knowledge Dissemination and Competitive Advantage in Industrial Agglomerations', *Journal of Economic Geography*, Vol.3, No.4 (2003), p.383.
[113] SA, X308/1/2/1/4/10, Firth's Report to Brown's Board, 23 February 1915.
[114] K.C. Barraclough, 'Sheffield and the Development of Stainless Steel', *Ironmaking and Steelmaking*, Vol.16, No.4 (1989), p.258.

with nickel and chromium steels in 1892.[115] Wartime developments with stainless steel were halted when production was restricted to divert chromium supplies to the manufacture of munitions in 1917.[116] The armistice 'permitted resumption of the research into the properties of new alloys which had been interrupted,' ushering in a new era of metallurgical developments in the Sheffield area.[117] From 1919 onwards, armaments research was no longer the driving force behind the discovery of new knowledge related to metallurgy. Instead, commercial considerations for specialist steels took precedence in the research facilities maintained by all of the armament manufacturers in Sheffield.

By investigating the patent records of the companies in this study it is possible to provide examples of metallurgical knowledge spun-off from armaments developments being utilised in alloy steels in the 1920s. At the Brown-Firth Research Laboratory work continued with stainless steel under the guidance of William Herbert Hatfield, who took over from Brearley during the War after a dispute with Firth over the commercial use of the material resulted in his resignation. A type of acid resisting steel was patented by Hatfield in 1922 which contained 18-24% nickel and 2-5% chromium, and claimed to be 'very suitable for use in the manufacture of pipes, vessels and other apparatus used in chemical and industrial engineering and parts of devices which are required to be non-corrodible.'[118] Undoubtedly an attempt to re-build pre-War networks, in 1923 Firth and Krupp arranged an exchange of their stainless steel knowledge and expertise, Brearley's original martensitic version of the material swapped for Eduard Maurer and Benno Strauss' austenitic stainless steel. The agreement was clearly formulated on older mentalities related to armaments and the use of home markets, with each company agreeing to remain outside of the other's country while dividing up the rest of the world's markets between them.[119] Building on this new information, in 1924 Hatfield developed 18/8 stainless steel, using 18% chromium and 8% nickel and marketed as 'Staybrite'.[120] After the introduction of Staybrite stainless steel in 1923, experiments continued at the Brown-Firth Research Laboratory, including

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[115] Barraclough, Stainless, p.258; Kelham Island Archive (KIA), MNHD/757, S.A. Main, 'The Contributions of Sir Robert Hadfield to Metallurgical Science and Technology, unpublished typescript, 1963.
[116] *The Ironmonger,* 19 October 1918.
[117] SA, X06/7/1/1/1, Firth-Brown 100 Years in Steel Book, 1937, p.67.
[118] British Patent 208,803/1922, p.2.
[119] Tweedale, *Steel City*, p.255.
[120] Tweedale, *Steel City*, p.255.

adjusting the content of nickel and chromium, and the addition of molybdenum and tungsten to develop new stain and heat resisting steels.[121] Another version of stainless steel came in 1928 from Hatfield which contained 18% nickel, 8% chromium and 0.6% tungsten, a material used in armour alloys by Brown from the 1890s.[122] The use of tungsten in alloy steels was part of the knowledge inherited by the Brown-Firth Research Laboratory from its inception, and allowed the material to be welded unlike Staybrite steel. During the 1920s Hatfield also worked on updated heat treatments for stainless steels in addition to developing the material, including one which allowed Staybrite steel to be polished.[123] Reflecting in 1936, a publication on the Brown-Firth Research Laboratory rightly claimed that ‘the laboratories may justly claim a share in the metallurgical developments of the last few decades.’[124] Against this backdrop, former armaments experts at Brown and Firth declined in importance with the development of new alloy steels. In the 1920s long time armour expert Tresidder turned his attention to the development of micrometers and angle measuring devices.[125] Elsewhere, innovations inspired by armour production continued to take place.

Cammell’s research in the 1920s focused on developing steel carburisation methods similar to those used with KC armour under the guidance of James McNeal Allen. The company had experience with several types of carburisation, but as their patent highlighted, ‘it is well known that whichever process be adopted very erratic and irregular results…occur too frequently.’[126] This built on Cammell’s knowledge of the process, and suggested using a salt bath, gasses and other chemicals to carburise steels.[127] Intriguingly, the patent does not mention the use of the method with armour. In contrast to their contemporaries who principally worked on the development of new alloy steels, this was an attempt to update a previously un-controllable and somewhat un-scientific treatment process. Cammell also researched nickel-chromium steels, one suggestion including 26-30% nickel and 16-22% chromium, building on their knowledge of utilising the two elements in armour steels. The resultant

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[121] SA, X06/7/1/1/1, Firth-Brown 100 Years in Steel Book, 1937, p.68.
[122] British Patent 316,394/1928.
[123] See British Patents 302,812/1927 and 333,237/1929.
[124] SA, X306/7/1/3/1, The Brown Firth Research Laboratory 1936, p.7.
[125] See British Patents 251,837/1925, 250,148/1926, 265,503/1926 and 325,963/1929
[126] British Patent 184,920/1921, p.3.
[127] British Patent 184,920/1921.

steel combined the two properties most desired in alloy steels of the time, being both heat and stain resisting[128]

Robert Abbott Hadfield, viewed as the initiator of the ‘age of alloy steels’ due to his pioneering work with manganese and silicon steels in the 1880s, was also active in the development of new alloy steels during the war and into the 1920s.[129] At the 1919 AGM Hadfield drew attention to the special steel products originating from work carried out in their research department. In addition to Heclon and Eron projectiles and ERA steel armour were ERA manganese steel, ERA non-magnetic steel, Hecla NK steel for aeroplanes and automobiles, Heclon and Heclon superior high speed steels, Galahad rustless steel (Hadfields’ first stainless steel), and a number of types for permanent magnets and electrical work.[130] Recounting Hadfields’ technological capabilities and giving an insight into his thoughts on running the company, Hadfield also drew attention to the near 400 patents held by him and his directors across the world. ‘In other words…’ he concluded, ‘…our profits are made, not merely by the handicraft of our Workers, but largely by the brains of the Management.’[131] Technological advance with alloy steels for any application was central to the business strategy adopted by Hadfield.

The development of Hadfields’ heat and stain resisting steels in the 1920s were grouped under the ‘ERA’ name used by the company for alloy steels since the 1890s. These were profiled by *The Engineer* in 1926, which stressed that ‘the precise composition of these steels is, obviously, not disclosed by the makers, but it may be said that they are based on the nickel-chromium class.’[132] All patented by Hadfield, the first to appear was ERA ATV steel, containing 1.3-8% silicon, 8-40% chromium and 1-10% tungsten, boasting heat and stain resisting properties and could be used in internal combustion engines.[133] This was followed by ERA LN, which claimed to incorporate heat and stain resistance ‘in an enhanced degree’ with the addition of manganese and nickel to the alloy steel’s silicon, chromium and tungsten content.[134] A third variation, ERA CR2, improved the ductility and strength of the previous two

[128] British Patent 276,249/1927.
[129] KIMA, MNHD/757, S.A. Main, ‘The Contributions of Sir Robert Hadfield to Metallurgical Science and Technology, unpublished typescript, 1963.
[130] SA, Hadfields Box 69, AGM Report 1919, pp.34-5.
[131] SA, Hadfields Box 69, AGM Report 1919, p.18.
[132] *The Engineer,* 9 April 1926, p.407.
[133] British Patent 220,006/1923.
[134] British Patent 232,656/1923.

ERA steels with 2-20% nickel, 5-30% chromium, 1-10% tungsten and the addition of up to 5% copper.[135] These materials found use with steam and gas turbines, and built on the vast pool of knowledge developed by Hadfield from metallurgical and armaments experimentation.[136]

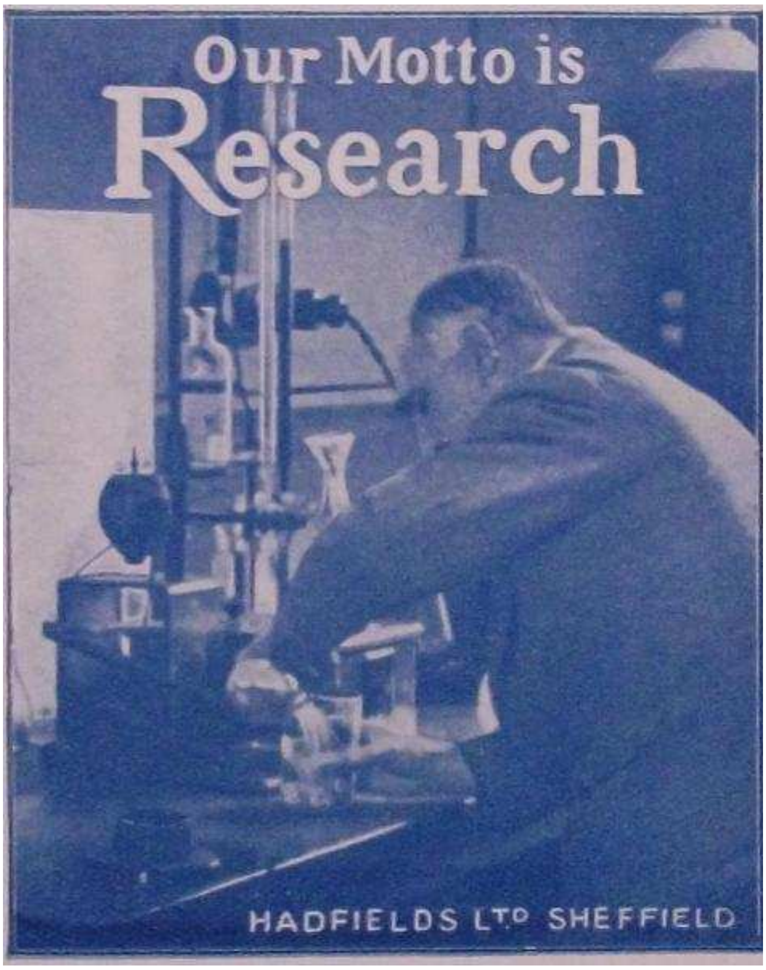

Figure 5.3: 'Our Motto Is Research' Hadfields' Advert 1927, Taken from the cover of their 1927 AGM Report.

In 1927, Hadfield's AGM brochure proudly displayed on the cover an image stating 'Our Motto is Research' (See Figure 5.3), and highlighted their new ERA HR heat resisting, and ERA CR non-corroding steels. Somewhat arrogantly in his speech Hadfield stated that 'inventors and discoverers of the first rank cannot be made…their genius is born in them and flourishes best when free from all restraint.'[137] A year later, Hadfield stated that

[135] British Patent 313,471/1928.
[136] Tweedale, Science, Innovation, p.75.
[137] SA, Hadfields Box 69, AGM Report 1927, p.27.

> The value of research is nowhere more clearly evidenced than in the field of metallurgy, and nowhere more highly appreciated than in the City of Sheffield, aided as it so ably is by the University. The work done by [Hadfields] research laboratories, and my colleagues working there, is an indication of the importance which we attach to this question, and a convincing example of the high level attained by industrial research in this City.[138]

While the University was an element of the armaments-metallurgy-steel innovation system centred on Sheffield before the Great War, as the 1920s progressed the system declined. The connections between people and institutions disappeared as patent agreements for armour and projectiles across the globe lapsed, and armaments-focused metallurgy was replaced by metallurgy which focused on peacetime products as the driving force behind innovation in the steel industry. The Steel Manufacturers Nickel Syndicate, important for continued supplies of nickel to support armaments production expelled its German members in 1918, and transitioned to supporting the development of special steels.[139] Principally the trans-national links in the system disappeared, evolving into a more localised innovation system connecting people, companies and trade associations linked to special steels in the Sheffield area. Armaments remained a part of this, yet their relative importance declined across the 1920s.

While there was a progressive decline in armaments utilising metallurgical research and development in the 1920s, the two fields could still draw upon each other for their mutual benefit when required. One design for armour from Hadfield in 1930 demonstrates this, drawing on his metallurgical knowledge dating back to the 1880s. His suggestion for the material incorporated 4% or less of manganese, 3% or less of silicon, and 2% or less of molybdenum to create a material suitable to defend against rifle bullets or for the protection of tanks.[140] The patent outline also suggests that molybdenum could be replaced with tungsten.[141] In this case, as with the others discussed here, their development and designs drew upon knowledge spun-off from

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[138] SA, Hadfields Box 69, AGM Report 1928, p.27.
[139] On the Steel Manufacturers Nickel Syndicate, see G. Boyce, ‘The Steel Manufacturers’ Nickel Syndicate Ltd., 1901-39: Assessing the Conduct and Performance of a Cooperative Purchasing Organisation’, *Australian Economic History Review*, Vol.38, No.2 (1998).
[140] British Patent 352,548/1930.
[141] British Patent 352,548/1930.

armaments research prior to the Great War. While the productive value of armaments declined throughout the 1920s, with practical developments explored and limited spin-off with AP projectiles and armour, the contribution of knowledge derived from using metallurgy to advance armaments technology assisted in the development of the next generation of special steels in Sheffield,. This was part of a continuum between metallurgical research and civilian and armaments applications for special steels which stretched back decades.

The limited spin-off from armaments developments in the 1920s has been suggested as a consequence of the 'follow-on imperative' in contrast to a longer period of 'breakthroughs' from the 1890s to the Great War. The criticism of follow-on developments in this period is that, while utilising sub-innovations, the lessons which can be passed onto the wider industry had diminished, leading to innovation solely for the refinement of armaments.[142] This is certainly the case with armaments and metallurgy as they took two different developmental paths. Work with AP projectiles refined their performance in the 1920s while the wider steel industry built on the pool of metallurgical knowledge passed down before the Great War. The next period of breakthroughs in armaments came between 1940 and 1965, with the development of jet aircraft, radar, atomic weapons, guided missiles, and the introduction of new electronics.[143] Arguably many of these innovations would have been impossible without the use of metallurgical knowledge in the development of alloys for specialised purposes, such as for stain and heat resistance. It is also important to not overlook the influence new metallurgical developments had on other industries outside of steel and armaments, Sayers in particular highlighting chemical engineering, the mining industry and the automobile industry.[144] This is not the limits of uses found for alloy steels in the inter-war years, for the railway and power-generating industries use was found for alloy steels in high-

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[142] C. Trebilcock, 'Science, Technology and the Armaments Industry in the UK and Europe, with special reference to the Period 1880-1914', *The Journal of European Economic History*, Vol.22, No.3 (1993), p.568. For a more critical view see M. Kaldor, *The Baroque Arsenal* (London, Andre Deutsch, 1982). Quoting Kaldor, Samuels also states of baroque technological change '…the incremental improvements, the incessant elaboration of existing weapons systems, and the ubiquitous "follow-ons" that preclude significant change – merely makes armaments more expensive, more complex, more cumbersome to support, and more distant from innovation.' See R.J. Samuels, *Rich Nation, Strong Army* (London, Cornell University Press, 1994), p.24.
[143] Trebilcock, Science, p.568.
[144] Sayers, Springs, p.284, p.286.

pressure boilers; for car manufacture heat and stain resisting alloys were used to improve the performance of crankshafts, camshafts and valves; and in the expanding aviation industry alloys with chromium, nickel and molybdenum were used to increase airflow to aircraft engines, and found use in the development of the first jet engines. Use was also found in the construction industry, stainless steel used for widespread fabrication work.[145] Hadfields attempted to diversify into car production as an outlet for their special steel capacity, with generally negative results.[146] In the 1920s, a decade in which breakthroughs with heat and stain resisting steels took place in Sheffield, commercial-focused metallurgical research replaced armaments-focused metallurgical research as the core area of investigation for the laboratories involved, utilising knowledge generated from successes and dead-ends explored in armaments developments.

Conclusion

During the Great War, the companies in the Sheffield armaments industry developed a number of collaborative defensive measures to maintain their position as custodians of the armaments knowledge they had developed in the two decades before the conflict. The use of pre-existing connections to develop a number of productive relationships, the development of training programs to induce further industrial capacity required for munitions, and innovations in response to productive issues or practical failures of their products used for warfare all served to help the companies remain an important part of the industry. Following the Battle of Jutland, the AP projectiles manufactured by Hadfields and Firth required further development to perfect their ability to perforate armour at an oblique angle. Each company embarked on further research, with collaborative developments required to produce a successful product. Beyond the War, work continued with limited spin-off of metallurgical knowledge, as more practical solutions were required for projectiles for oblique attack. Away from armaments, the metallurgical spin-off from research and development efforts in the industry resulted in a broad knowledge base which was utilised with heat and stain resisting steel experiments, continuing a long

[145] Tweedale, *Steel City*, pp.241-2.
[146] See G. Tweedale, 'Business and Investment Strategies in the Inter-War British Steel Industry: A Case Study of Hadfields Ltd and Bean Cars, *Business History*, Vol.29, No.1 (1987), pp.47-72.

established practice of both armaments-based and commercial-based developments influencing each other. As the relative importance to the industry of armaments declined, so too did the armaments-metallurgy-steel innovation system, evolving into one more focused on the special steel industry in the Sheffield area. Technological developments remained an important part of the industry in the 1920s, even with the decreasing demand for their products in the home and international market. The final chapter now turns to an exploration of the business and management of armaments during this period.

Chapter 6: The Business and Management of Armaments 1914-1930

As the previous two chapters have demonstrated, the individual and combined efforts of the armaments companies to protect against the uncertainty of government procurement patterns and to maintain their position as custodians of the technology involved were key elements of the armaments industry prior to and during the Great War. These efforts were predominantly proved effective when enacted during times of high demand from both home and overseas customers. However, the Great War and its aftermath in the 1920s fundamentally changed the nature of the armaments business, rendering most of the industry's defensive measures inadequate and ineffective. As Hornby has suggested, 'generally after 1918, it may be said, that with the loss of home and overseas demand, the armament industry reached the verge of extinction.'[1] The armaments industry had, in the view of Packard, an identity crisis after the Great War.[2] The armaments producers also suffered a double blow due to a tandem decline in the steel industry. As Pollard highlights:

> The iron and steel industry was another of the basic staple trades which suffered a decline in exports. Moreover, the war had created a large surplus capacity and the post-war boom of 1919-20 burdened it with much watered capital, and this hung like a millstone around its neck until the re-armament of the late 1930s.[3]

Examining the business and management of the armaments industry from the Great War to 1930, this chapter will examine three key areas. Firstly, there will be an examination of the decline and death of special relationships with the Government in this period, and the connections armaments companies had with the Admiralty. Secondly, the chapter will explore the declining business of the armaments companies during the 1920s, and their limited successes in the international market. Finally, an investigation into the changing structure of the industry through to 1930, and the managerial stagnation of the companies involved.

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1 W. Hornby, *Factories and Plant* (London, Longmans, Green and Co, 1958), p.25.
2 See E.F. Packard, *Whitehall, Industrial Mobilisation and the Private Manufacture of Armaments: British State-Industry Relations, 1918-1936* (London School of Economics, Unpublished PhD Thesis, 2009), Chapter 3: From Diversification to Rationalisation: The Arms Industry's Identity Crisis, 1918-27.
3 S. Pollard, *The Development of the British Economy 1914-1990 (4th Edition)* (London, Edward Arnold, 1992), p.52.

The Death of Special Relationships: Armourers and the British Government 1914-1930

At the commencement of the Great War, there was a general failure of industrial mobilisation in Britain due to a reliance on the companies featured on the War Office and Admiralty procurement lists.[4] In this regard, the special relationships of the pre-War period were tested, with disastrous consequences. Adams has criticised the supply ministries for a 'failure of imagination, an inability to conceive of the problem which faced them, outside of the narrow framework of tradition and precedent to which they bound themselves.'[5] There was also criticism levelled at previous government policy by the companies involved. Robert Abbott Hadfield used his company AGM in March 1915 to attack Richard Haldane, the former Secretary of State for War, and the lack of capacity to produce Army shells. He drew attention to the dismantling of their shrapnel shell shop during Haldane's tenure which could have been expanded to produce 1 million rounds per year at the start of the conflict.[6] The shell scandal in May of the same year led to the formation of the Ministry of Munitions and a change in procurement strategy for army materials.[7] During the conflict, the Navy retained control of their own supplies. The Ministry of Munitions was, in the words of David Lloyd-George, a businessman's organisation, with many men of 'push and go' recruited from private industry and remaining on their company's payroll, limiting the control Whitehall had over them.[8] From John Brown, Charles Ellis 'relieved Eric Geddes of responsibility for the provision of guns and gun equipment' in 1916 and remained with the Ministry until the end of the War.[9] Major Harry Strange of Firth was also used by the Ministry as Director of Gun Ammunition Filling from July 1915 to February 1916.[10] Cammell's chairman William Lionel Hichens visited Canada on behalf of the Ministry of Munitions in

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[4] C. Trebilcock, 'War and the failure of industrial mobilization: 1899 and 1914' in J.M. Winter, *War and Economic Development, Essays in the memory of David Joslin* (Cambridge, Cambridge University Press, 1975). For a general overview of industrial mobilisation across Europe in the early months of the War, see H. Strachan, *The First World War Volume 1: To Arms* (Oxford, Oxford University Press, 2003), Chapter 11: Industrial Mobilisation.

[5] R.J.Q. Adams, *Arms and the Wizard: Lloyd George and the Ministry of Munitions 1915-1916* (London, Cassell, 1978), p.14.

[6] Sheffield Archives (SA), Hadfields Box 9, Hadfields AGM Report 1915, pp.4-5.

[7] The shell scandal is covered in J.D. Scott, *Vickers: A History* (London, Weidenfeld and Nicolson, 1962), pp.100-103.

[8] C. Wrigley, 'The Ministry of Munitions: an Innovatory Department' in K. Burk, *War and the State: The Transformation of British Government, 1914-1919* (London, George Allen and Unwin, 1982), pp.40-41.

[9] Adams, *Arms and the Wizard*, p.48.

[10] SA, X306/1/2/3/1/4, Firth's Directors Meeting Minute Book No.4, 27 July 1915, p.270.

late 1915.[11] While looking to utilise as much of Britain's industrial capacity as possible, the specialist armaments producers' knowledge and experience was still required to assist in training and mobilisation.

Prices for shells were reconsidered by the Ministry of Munitions in December 1915, and several contracts for continuous supply were terminated. Investigations at Armstrong, Vickers, Firth, Hadfields and the Projectile Company highlighted differences in the prices charged per shell, after which standard prices for each product were introduced.[12] This standardisation of prices coupled with the vast demands for war materials swept away any hierarchy of special relationships in the armaments industry, with all capacity needed in full production to meet requirements. While important for the most highly specialised products, principally armour and armour piercing projectiles, private industry was not well equipped to deal with the deluge of orders for general shells. In this regard, the special relationships of the pre-War period were relied upon too well in the early months of the conflict. Over the next decade, the nature of state-armaments industry relations continued to evolve.

As peace came many orders were cancelled, and in the winter of 1918-19, large stockpiles of military stores of all kinds were available.[13]. At Brown, it was reported that 'we have large numbers of gun forgings and considerable weight of shell material cancelled and it is somewhat difficult to find work for departments which were handling these orders.'[14] At their shipyards, Brown also had contracts for five destroyers cancelled in 1919, their last orders for British Navy vessels for a decade.[15] At Cammell, one battlecruiser, nine submarines, two flotilla leaders and four submarine engines were all cancelled at the end of the War. Some of the orders had been in an advanced state of construction, and had to be scrapped on their slipways.[16] Reflecting on the industrial nature of the War in early 1919, *The Engineer* noted that 'The whole area of Sheffield and neighbouring works has been one great arsenal throughout the war, pouring out day and night almost every kind of munitions

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[11] Wirral Archives (WA), ZCL/5/43, Cammell Laird Minute Book No.10, 13 October 1915, p.257.
[12] Scott, *Vickers*, p.127.
[13] Adams, *Arms and the Wizard*, p.185.
[14] SA, X308/1/2/1/3/14, Brown's Managing Directors Report 28 November 1918.
[15] A. Slaven, 'A Shipyard in Depression: John Browns of Clydebank 1919-1938' in R.P.T. Davenport-Hines (Eds.), *Business in the Age of Depression and War* (London, Frank Cass, 1990), p.127. Slaven provides an overview of the issues Brown faced in shipbuilding during the 1920s, in addition to their armaments and steel issues discussed in this chapter.
[16] WA, ZCL/5/266/17, List of Government Ships Built by Cammell Laird, n.d., 1920s.

required.'[17] Against this backdrop, the relative position of the Sheffield armaments industry was in serious doubt in the future peace, a situation not lost on the companies involved.

As soon as the conflict ceased, the armaments companies began pressing for answers about the future of the industry. William Lionel Hichens, chairman of Cammell, wrote to the Government in December 1918, calling for the need to retain the Coventry Ordnance Works (COW) as a nucleus factory for future armaments needs, and that most of the works could be utilised for peace products. He urgently pressed for a response; highlighting that is was increasingly difficult to retain their skilled staff which years of training had produced with an empty order book, most of their work having been cancelled at the time of the armistice. Reminding the Government of their use of COW during the War, Hichens suggested that:

> It would be grossly unjust if, after having taken every advantage of the organisation and facilities possessed by the Coventry Ordnance Works, the Government were to throw them on the rubbish heap like a sucked orange.[18]

Hichens also used the company OGM in April 1919 to attack the Government's lack of direction for the industry:

> We are wholly in the dark as to what the future policy of the Government in regards to private armament firms is to be…My point is, at the moment, that the Government ought not to keep us dangling indefinitely at the end of a string…they ought to make up their minds promptly, on the policy they intend to adopt. And meanwhile we may at least fairly claim I think, that if they cannot give us work for those parts of our factories which are exclusively equipped for armaments production and which must be retained until some policy has been decided upon by the Government, they should enable us to maintain a nucleus organisation.[19]

He also stressed that, given much of Sheffield had converted back to commercial production, 'it is only in the highly specialised armament shops that we are paralysed by the indecision of the Government.'[20] In March 1919

[17] *The Engineer*, 3 January 1919, p4.
[18] The National Archives (TNA), CAB/24/72/29, William Lionel Hichens to The Secretary, War Cabinet, 18 December 1918.
[19] *Journal of Commerce*, 10 April 1919.
[20] *Journal of Commerce*, 10 April 1919.

Brown's Works Committee suggested there was a 'necessity of paying special attention to our general trades now that armour cannot be reckoned on.'[21] The situation with projectiles was the same. Robert Abbott Hadfield had been providing agitation to the British Navy from mid-January 1919 for some assurance to the future demands for armour piercing (AP) projectiles. In writing to the Director of Navy Contracts, he remarked:

> We called your attention to our letter…of January 16th, in which we pointed out that this manufacture represents a highly complex and specialised art…There is probably no more difficult process in the Metallurgical Art than that of hardening an Armour-Piercing Shell, the complete manufacture of which involves a series of operations from the making of the Special Steel onwards, representing the accumulated experience derived from thirty years of research and experiment.[22]

The Admiralty's response came in October 1919, regarding the possibility of paying subsidies to Hadfields for the maintenance of their plant. A resultant meeting between Hadfields, Firth and the Admiralty at the end of the month centred on what terms the two companies could maintain their projectile plant, with Hadfields suggesting a subsidy of £50,000 per annum, or an agreement to keep 20% of their projectile capacity in production.[23] Despite the discussion, no new or revised agreement was forthcoming. Instead, former agreements continued to be extended. Hadfields' last agreement with the Admiralty had been signed in January 1913 for a period of three years, and had been extended in December 1915 through to January 1919 under the same conditions.[24] The 1913 agreement promised Hadfields half of all the orders to the Trade for larger calibre AP and common pointed capped (CPC) projectiles.[25] Given the general uncertainty from the Admiralty regarding their future requirements for AP projectiles, the contract was extended for six months in January 1919, while in correspondence the Admiralty highlighted that:

> In view of the uncertain position at present existing as to the types and descriptions of Naval Shell which will be required in the future, it is not

[21] SA, X308/1/4/1/2/4, Brown's Works Committee Agendas and Papers, 14 March 1919.
[22] SA, Hadfields Box 33, Robert Abbott Hadfield to Director Of Contracts, Admiralty, 11 October 1919.
[23] SA, Hadfields Box 33, A.B.H. Clerke Notes, 23 October 1919.
[24] SA, Hadfields Box 103, Hadfields Shell Agreement, January 1913 to January 1916, Hadfields Shell Agreement, January 1916 to January 1919.
[25] SA, Hadfields Box 103, Hadfields Shell Agreement, January 1913 to January 1916

possible to consider at the moment the question of entering into a fresh agreement with you.[26]

The contract was further extended in July 1919 for six months, February 1920 for six months, July 1920 for one year, and in August 1921 for a final six months.[27] After the agreement lapsed in 1922, it was not renewed.

Despite this agitation from private industry, the government knew the value of maintaining their sources of supply. As the Admiralty recorded in March 1919, 'The retention of naval supply under Admiralty control [is] an essential part of naval strategy.'[28] However, there were limitations placed on their ability to procure weapons in the future. The ten year rule, implemented from 15 August 1919 instructed the service departments to plan their budgets on there being no wars for the next ten years.[29] Furthermore, Sir Eustace Tennyson d'Eyncourt, then Director of Naval Construction, highlighted the need to retain the capacity of the armaments companies for armour, and wrote in 1919 of the product that it was:

> 'An article which is required solely for war purposes and requires the greatest skill, not only of the chemist and the metallurgist but also in the actual manipulation by the skilled workers…if provision…is not made, we shall get left behind.'[30]

Davenport-Hines highlights that 'The history of the next decade and a half is that of these recommendations being ignored.'[31] This may, in part, be accounted for by the various approaches to procurement that were attempted in the early 1920s.[32]

By August 1920, the prospects for the armaments industry appeared favourable. The Director of Naval Construction invited Vickers, Armstrong, Cammell and Brown to discuss the manufacture of machinery, guns, armour and hulls of four new 45,000 ton battlecrusiers. The armour production would be split between the four, and as Vickers could not construct vessels of the size

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[26] SA, Hadfields Box 103, Hadfields Shell Agreement, January 1919 to July 1919.
[27] SA, Hadfields Box 103, Hadfields Shell Agreements for July 1919 to March 1922.
[28] Quoted in G.A.H. Gordon, *British Seapower and Procurement between the Wars: A Reappraisal of Rearmament* (Annapolis, Naval Institute Press, 1988), p.19.
[29] R.P.T. Davenport-Hines, *The British Armaments Industry during Disarmament* (Unpublished Thesis, University of Cambridge, 1979, p.23.
[30] Sir Eustace Tennyson d'Eyncourt, Memorandum on 'Future Provision for Keeping Prepared', 8 September 1919 DEY/21, cited in Davenport-Hines, *Disarmament,*p.28.
[31] Davenport-Hines, *Disarmament*, p.28.
[32] For an overview see Gordon, *Seapower,* Chapters 3 to 6; Packard, *Whitehall,* pp.75-78; Davenport-Hines, *Disarmament,* p.21.

required, each of the other three would be invited to construct at least one of the new generation of ships. The armour orders for the four ships were issued to the trade in October 1921, but were quickly cancelled due to changes in the international theatre.[33]

Table 6.1: Admiralty Expenditure on Armaments 1920-1930, and Proportion to Trade (£m)

Year	Government Factories	Trade	Percent to Trade
1920-1921	1.8	4.2	70
1921-1922	1.7	2.3	57
1922-1923	1.3	1.1	47
1923-1924	1.3	1.4	51
1924-1925	1.4	1.2	46
1925-1926	1.5	1.2	44
1926	1.1	1.1	50
1927	1.4	1.7	58
1928	1.7	1.2	42
1929	1.6	1.0	40
1930	1.5	0.8	36

Source: Adapted from Davenport-Hines, British Marketing of Armaments, p.148.

The Washington Naval Treaty severely restricted the Navy's procurement plans, and most contracts where rapidly put on hold and then cancelled. While in the early 1920s there were efforts by the League of Nations towards universal disarmament, the Washington Naval Treaty was the only successful agreement to restrict the construction of weapons.[34] Signed on 6 February 1922, the Treaty between Britain, the United States, Japan, France and Italy agreed to limit their capital ships in their fleets to the ratio of 5:5:3:1.75:1.75, limit the size of vessels to no more than 35,000 tons, and

[33] K. Warren, *Armstrongs of Elswick: Growth in Engineering and Armaments to the Merger with Vickers* (London, Macmillan, 1989), pp.200-1.

[34] See A. Webster, 'Making Disarmament Work: The Implementation of the International Disarmament Provisions in the League of Nations Covenant, 1919-1925', *Diplomacy and Statecraft,* Vol.16, No.3 (2005), pp.551-569; A. Webster '"Absolutely Irresponsible Amateurs": The Temporary Mixed Commission on Armaments, 1921-1924', *Australian Journal of Politics and History*, Vol.54, No.3 (2008), pp.373-388; and K. Tenfelde, 'Disarmament and Big Business: The Case of Krupp, 1918-1925', *Diplomacy and Statecraft*, Vol.16, No.3 (2005), pp.531-549.

implement a ten year break on new ship construction.[35] As shown in Table 6.1, this saw a reduction in Admiralty expenditure to private trade until 1930, and severely damaged the prospects for private manufacturers of armaments. Vickers' official historian has summarised the situation for the company after Washington remarkably well:

> For Vickers the Washington Treaty marked the final termination of an era. It had for some time hardly been realistic to keep on the large expert staff, the whole great apparatus of research and development upon which armament capacity so depended: now it became impossible. When every possible transfer of skilled men to non-armament work had been made, there were still dismissals – 'a very large reduction' – and large as it was, it was worse still in that it meant the breaking up of an organisation, and worst of all because it brought home to everyone in the company an anxiety which up to now had been confined to the board room and its annexes – a chronic anxiety about the basic conditions of survival. Nothing like this had every happened before.[36]

It was certainly the beginning of the end for some armaments companies. Bastable has suggested that neither Vickers nor Armstrong 'could survive the post-1918 context. No entrepreneurial skill could save them, and by 1926 both were bankrupt.'[37] Elsewhere in the industry, order cancellations were common. At Beardmore, of the £4.2million of orders received by November 1921, only £11,000 was executed owing to the signing of the Washington Treaty.[38] The Treaty also stifled expansion plans for the armour producers in Sheffield once their orders were cancelled.

In 1920, Brown commenced a reconstruction programme, and their Works Committee suggested that the armour plant should be capable of producing 5,000 to 7,000 tons of armour per year.[39] The following April, the Works Committee recorded their anticipation that new armour orders would be forthcoming, which 'it was quite hoped would improve matters and stimulate business.'[40] Once details of the potential armour orders were known, £25,000

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[35] Packard, *Whitehall,* pp.51-2.
[36] Scott, *Vickers*, p.144.
[37] M. J. Bastable, *Arms and the State: Sir William Armstrong and the Remaking of British Naval Power, 1854-1914* (Aldershot, Ashgate, 2004), p.165.
[38] Davenport-Hines, *Whitehall,* p.137.
[39] SA, X308/1/4/1/1/3, Brown's Works Committee Meeting Minutes, 25 October 1920
[40] SA, X308/1/4/1/1/3, Brown's Works Committee Meeting Minutes, 4 April 1921.

was approved to be spent on Brown's armour department to make them capable of producing the size and weight of plates required.[41] When the orders were finally received in October 1921 for 9,700 tons of armour, the work was anticipated to keep their armour plant in operation for the next two years. One of the four new battleships to be built was also ordered from Brown's Clydebank shipyard.[42] Their adulation was short-lived as the orders were suspended in November, Brown recording that they 'might or might not end in cancelment [sic], but had for the present very disastrous results on the operation of the company.'[43] The stoppage on work for the four battlecruisers after the Washington Treaty was described in 1922 by Brown's chairman Lord Aberconway as 'a serious matter, not only for John Brown and Co, but for Sheffield.'[44] The following year at their AGM, Aberconway dismally proclaimed that 'the city was practically abandoned by the Government owing to the consequences of the Treaty of Washington.'[45]

An unknown Brown's director produced a memorandum in 1922 in which issues for the future of business in Sheffield were highlighted. It opened by stressing that:

> the effects are undoubtedly most serious at Sheffield, since Sheffield has always been the chief centre for the manufacture of the armour, guns, heavy steel forgings of all kinds, [and] shell for warships.[46]

At the time of the new naval orders being placed, unemployment in Sheffield was the worst in living memory, with around 40,000 men out of work. It had been hoped that the new orders would give many of them employment.[47] The memorandum also stated that 'the placing of the orders for the four new warships removed a load of anxiety from the minds of the Sheffield manufacturers, and was received with satisfaction and delight by all classes of the workmen.[48] The unknown author stresses that the suspension of naval work should be reversed and work allowed to continue 'without prejudice to any

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[41] SA, X308/1/4/1/1/3, Brown's Works Committee Meeting Minutes, 26 September 1921.
[42] SA, X308/1/4/1/1/3, Brown's Works Committee Meeting Minutes, 24 October 1921.
[43] SA, X308/1/4/1/1/3, Brown's Works Committee Meeting Minutes, 28 November 1921.
[44] *The Times*, 28 June 1922.
[45] *The Times,* 27 June 1923.
[46] SA, X308/1/2/1/10/1, Memorandum on Suspension of Naval Orders, n.d., probably early 1922.
[47] SA, X308/1/2/1/10/1, Memorandum on Suspension of Naval Orders, n.d., probably early 1922.
[48] SA, X308/1/2/1/10/1, Memorandum on Suspension of Naval Orders, n.d., probably early 1922.

ultimate decision that may be reached on the completion of the ships' as similar steps had taken place in America and Japan.[49] It was stated that 'it has taken years to train the officials and men to carry out the highly skilled metallurgical and mechanical operations required' and that the plant cannot 'be used for work other than that for which it was designed.'[50] Despite the hope of the director to resume work and keep the plant in operation, no changes were forthcoming. The cancellations also had an effect on Cammell's armour plant expansion and production.

At a board meeting in November 1921, Cammell proposed a scheme to bring their armour department up to date at a total cost of £250,000, ultimately cancelled the following month 'in consequence of work on the armour order being in abeyance.'[51] Hichens announced his disdain at the situation at the company OGM in 1922. It was believed that the orders received in late 1921 would keep their armour plant in operation for two years, 'but the Washington Conference has dashed our hopes to the ground, and now the most we can expect is that orders will be placed for two much smaller ships, after which there will be a naval holiday until 1932.'[52] The company could not maintain their armour shops idle for ten years, and Hichens in his closing remarks called on a government subsidy during the naval holiday.[53] The lack of subsidies continued into 1925, when Hichens again attacked the government, stating at their OGM that 'The time has I think come when the Government should decide upon a policy in respect of the armour plate makers.'[54] In 1925 Admiral Sir Emle Chatfield, Controller of the Navy, gave a speech at Cutlers Hall in Sheffield, highlighting that 'It would be a bad day for the Empire if the plant and the skilled men who designed it, who brought it into existence, and who used it, were allowed to decay.'[55]

An agreement between the Admiralty and the armour manufacturers to protect the armour business was ultimately signed the same year with the

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[49] SA, X308/1/2/1/10/1, Memorandum on Suspension of Naval Orders, n.d., probably early 1922.
[50] SA, X308/1/2/1/10/1, Memorandum on Suspension of Naval Orders, n.d., probably early 1922.
[51] WA, ZCL/5/44, Cammell Laird Board Meeting Minute Book No.11, 9 November 1921, 7 December 1921.
[52] *Journal of Commerce*, 6 April 1922.
[53] *Journal of Commerce*, 6 April 1922.
[54] *Journal of Commerce,* 25 March 1925.
[55] SA, Hadfields Box 69, Hadfields Annual General Meeting Report 1926, p.13.

armour manufacturers to last for one year, and was renewed annually into the 1930s. The companies involved promised to maintain their plant and skilled staff ready to produce a minimum specified quantity of armour per year, and continue to be available for development and experimental work. In return, the Admiralty promised to only order from them, so long as the companies could meet the requirements satisfactorily regarding price, quality, and delivery.[56] That year, subsidies were paid to the armour manufacturers, with £41,365 for Cammell, £49,078 for Brown, and £86,000 each for Vickers and Armstrong.[57] The links between manufacturers were no longer characterised by special relationships; as the armour agreement demonstrated, in order to protect capacity the links between the state and private industry were more 'necessary' than anything extraordinary.

In projectiles, arrangements were also made to protect capacity for any future requirements from 1922. Changes in the industry, with former producers closing or abandoning manufacture had left just Hadfields and Firth in a position to manufacture large calibre AP projectiles. Furthermore, the plant involved was highly specialised and not easily adaptable to commercial work. The plant Hadfields maintained included units and machines which had been specially developed for projectile production and represented a capital outlay of some £500,000. The company continually stressed the specialty of their plant, and emphasised that none of the machinery could be adapted for commercial purposes. At Firth's Gun Works, principally based on forging technology, commercial products had re-entered production in 1919.[58] Following a conference between the Admiralty, Hadfields and Firth in March 1922, a new collaborative arrangement was signed between the three parties. Each agreed to maintain their productive capacity and trained staff for AP projectiles until the end of 1925, with minimum requirements for weekly output and skilled personnel working double shifts also imposed (See Table 6.2). In addition to the maintenance of the two companies' projectile plants, Hadfields would receive

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[56] For more on the armour agreement, see Davenport-Hines, *Disarmament*, pp.225-230, and D. Edgerton, 'Public Ownership in the British Arms Industry, 1920-1950' in R. Millward and J. Singleton, *The Political Economy of Nationalisation in Britain 1920-1950* (Cambridge, Cambridge University Press, 1995), p.166.

[57] R.P.T. Davenport-Hines, 'The British Marketing of Armaments 1885-1935' in R.P.T. Davenport-Hines, *Markets and Bagmen: Studies in the History of Marketing and British Industrial Performance 1830-1939* (Aldershot, Gower Publishing, 1986), pp.153-4.

[58] SA, Hadfields Box 33, A.B.H. Clerke Notes, 23 October 1919.

5/8ths and Firth 3/8ths of the orders forthcoming for the Navy.[59] The agreement was renewed in January 1926 for a further five years.[60] As part of the renewal, the companies had to allow free entrance of Government inspectors to their hardening and treatment shops. Both were adverse to the request, but reluctantly allowed their admission.[61] Reflecting after the start of rearmament in 1936, Clerke remarked of their relationship with the Admiralty: 'when the time came to renew these agreements…we had of course to accept it "faute de mieux" [for lack of something better].'[62] Once again, the government's relationship with the projectile manufacturers was no longer characterised by specialty, but by the necessary retention of capacity. This necessity was replicated in other industries which had declining membership. In optical munitions, Sambrook has demonstrated how the number of producers in the industry had shrunk to just one by 1923, and the industry entered into a period of 'hibernation during which the ability to produce all kinds of optical munitions would be sustained, even though output remained at a low level for the remainder of the 1930s.'[63]

Table 6.2: Capacity to be Retained for Weekly Projectile Production at Hadfields and Firth, 1922-1930

Hadfields	Firth
250 - 15 inch or 16 inch, or 500 - 8 inch	150 - 15 inch or 16 inch
500 - 6 inch	350 - 8 inch
1000 - 4 inch	270 - 7.5inch, or 400 - 6 inch, or 500 - 4.7 inch, or 500 - 4 inch

Source: SA, Box 103, A.B.H. Clerke to Secretary Of The Admiralty, 21 July 1925; Box 103, Shell Agreement January 1926 to December 1930.

For the companies involved, the tumultuous changes in the environment in which they operated meant their pre-war approach to armaments, in which

59 SA, Hadfields Box 103, A.B.H. Clerke to Secretary Of The Admiralty, 21 July 1925; Hadfields Box 64, P.B. Brown to Robert Abbott Hadfield, 18 September 1923. This agreement appears to be verbal only, as the only references to it appear in letters. In the Hadfields' records, a folder of all the agreements between the Admiralty and Hadfields skips over 1922-1925 in the listings.
60 SA, Hadfields Box 103, Shell Agreement, January 1926 to December 1930.
61 SA, X306/1/2/3/1/6, Firth's Directors Meeting Minute Book No.6, 22 December 1925, p.59.
62 SA, Hadfields Box 31, Clerke to Hadfield, 11 March 1936.
63 S.C. Sambrook, *The Optical Munitions Industry in Great Britain, 1888-1923* (London, Pickering and Chatto, 2013), p.204.

research and development was funded in-house from profits made from armament sales, was completely untenable. In order to maintain capacity for both experimentation and production, the government was forced to pay the armaments companies and fundamentally change their relationship fostered over the past two decades. Several interpretations of this advancing state-industrial relationship have been put forward. Davenport-Hines has extended the use of the special relationships paradigm into the 1930s, highlighting that the Great War was a watershed in the industry, and that 'the 'special relationship' which had evolved in 1888-1914 was shattered…and the informal personal contacts on which the relationship had relied were forced into a more impersonal institutional framework.'[64] He also suggests that these blows to the special relationship caused the exit of several specialist armaments companies in the following decade.[65] However, Davenport-Hines still maintains the 'special relationships' badge for what he observed. More recently, Edgerton has rightly suggested that revisions need to be made to the view of inter-war armaments.[66] He has also advanced that 'the navy declined relative to the forces as a whole, and the naval-industrial complex declined faster relative to the arms industry as a whole.'[67] Packard has suggested the system of closeness and cooperation before the Great War between the Government and private industry was replaced by one characterised by 'struggle and stagnation' from 1918 to the start of rearmament in the 1930s.[68] He also advances that the Government favoured their relationships with Vickers and Armstrong over other smaller producers, somewhat overlooking the projectile agreement discussed above.[69] Packard has highlighted that:

> The Admiralty clearly wished to help its main suppliers and continued to place a large amount of trust in the private armaments industry or, at least, certain key firms. To some extent, this demonstrated the endurance, or even a strengthening, of the naval-industrial complex in the inter-war years.[70]

[64] Davenport-Hines, Marketing, p.146.
[65] Davenport-Hines, Marketing, p.156.
[66] D. Edgerton, *Warfare State, Britain 1920-1970* (Cambridge, Cambridge University Press, 2006, pp.33-41.
[67] Edgerton, *Warfare State*, p.21.
[68] Packard, *Whitehall*, p.10.
[69] Packard, *Whitehall,* p.27.
[70] Packard, *Whitehall,* p.57.

Overall, the suggestion that the government retained a special relationship with the trade regarding armaments procurement in the 1920s is difficult to substantiate. While the industry provided important productive facilities, technical advice and advancement, and key armaments experts to the Ministry of Munitions during the Great War, the cracks were starting to show at the end of the conflict, exacerbated by the industry's failure to manufacture what was ordered in the early months of war. The government struggled to work out what to do with armaments once peace arrived, and somewhat more tentative, uncertain special relationships continued before the agreeing to pay subsidies to protect the capacity of private industry. Once the Washington Naval Treaty was signed, the special relationships which had been a characteristic of the industry since the 1880s died, in its place grew what is best described as a 'necessary relationship' in which capacity was supported while orders evaporated. This had a serious effect on the business of all the armaments producers in Sheffield, which the following section will explore.

The Decline of Armaments Business 1914-1930

The deluge of orders during the Great War provided high profits for all the armaments industry, though these were not as high as they could have been due to the introduction of the Munitions Levy and Excess Profit Duty during the conflict. Introduced in 1915, this was initially set at 50 per cent of any amount over the average profits made in two of the last three years before the War. The rate was increased to 60 per cent in 1916, and 80 per cent in 1917. It was reduced to 40 per cent in 1919 and finally abandoned in 1921 against the backdrop of declining economic conditions.[71] The 1920s were a difficult decade for all the armaments companies, the profits of the Great War a distant memory once orders disappeared. An analysis of the profits of Vickers and Armstrong between 1914 and 1924 using return on capital employed as a measure instead of published profitability also demonstrates a decline in profitability after the end of the conflict, something reflected across the industry.[72] Vickers' armaments business declined during the 1920s, last paying a dividend in 1923, while Armstrong paid no dividends from 1925, and Beardmore paid none for 10 years

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[71] For a full discussion of EPD, see M.J. Daunton, 'How to Pay for the War: State, Society and Taxation in Britain, 1917-24', *English Historical Review*, Vol.111, No.433 (1996), pp.882-919.
[72] A.J. Arnold, '"In Service of the State"? Profitability in the British Armaments Industry 1914-1924, *Journal of European Economic History*, Vol.27, No.2 (1998), pp.285-314.

after 1921.[73] The Sheffield steel industry as a whole may have been in an even worse position than it found itself were it not for the rise in stainless steel production, a legacy of the research and development commitment of the armaments industry before the Great War.[74] Nevertheless, the 1920s were difficult for all companies, especially the armour producers.

Table 6.3: Brown's Atlas Works Invoiced Output, Profit and Dividends 1914-1930

	Atlas Works (£,000s)		All Brown's Business	
	Commercial (Percentage)	**Armour (Percentage)**	**Profit (£)**	**Ordinary Dividend (%)**
1914-1915	791 (47)	905 (53)	521,007	12½
1915-1916	1,160 (76)	375 (24)	485,120	12½
1916-1917	1,874 (77)	570 (23)	494,029	12½
1917-1918	2,238 (98)	44 (2)	453,317	12½
1918-1919	2,292 (100)	0 (0)	467,171	12½
1919-1920	1,901 (87)	282 (13)	378,808	12½
1920-1921	2,431 (97)	71 (3)	331,920	10
1921-1922	821 (94)	56 (6)	210,407	5
1922-1923	658 (85)	115 (15)	212,294	5
1923-1924	881 (93)	65 (7)	212,230	5
1924-1925	961 (79)	257 (21)	211,233	5
1925-1926	*No data*	437 (-)	91,419	Nil
1926-1927	*No data*	81 (-)	6,589	Nil
1927-1928	*No data*	88 (-)	67,389	Nil
1928-1929	*No data*	43 (-)	87,262	Nil
1929-1930	*No data*	1 (-)	24,184	Nil

Sources: SA, John Brown's Managing Directors Reports 1914-1925; Firth-Brown Armaments Production Records 1915-1945. Brown's profit figures were very kindly provided from Geoffrey Tweedale's private collection.

Brown's record from 1914 to 1930 reflects the difficulties of being an armour producer at the time (See Table 6.3). The high point of armour output was in 1914-15, after which their production never reached the same proportion

[73] Warren, *Armstrongs*, pp.223-4. An excellent overview of Vickers' problems is provided in R.P.T. Davenport-Hines, *Dudley Docker: The Life and Times of a Trade Warrior* (Cambridge, Cambridge University Press, 1984), Chapter 8: Armaments, Electricity and Rolling Stock.
[74] R.S. Sayers, 'The Springs of Technical Progress in Britain 1919-39', *The Economic Journal*, Vol.60, No.238 (1950), p.289.

and value again. By focusing on a single product, the company was hit hard after the Washington Treaty, the only brief revival occurring in the mid-1920s with the construction of two new capital ships. The official history of John Brown observed that in the 1920s, 'The Atlas Works produced some heavy armour for H.M.S. *Rodney*, but there was nothing else of much importance to record.'[75] When Brown passed their annual dividend in 1926 it was the first time they had done so for 50 years.[76]

This decline in fortunes was not unexpected at the company. Brown's chairman, Baron Aberconway, understood the issues the armaments firms would face once the peace came, predicting in early 1915 that:

> when the war was over it might be years before any of the armament firms got an order for battleships, guns, armour plates, or many of the things which they now produced in such large numbers. They might find that after a short period in which they would make a little money they might practically be without profits at all.[77]

Not that orders for armour were easy to come by during the Great War, a principally land based conflict. The air of uncertainty around future demand was summed up in a Brown's report in August 1916 which stated 'Armour orders may come forward at any time.[78] Some orders were placed with all the armour manufacturers in March 1917 for HMS Hood being built at Clydebank, sharing 1,100 tons between the five armour producers.[79] Once the War was over, the future of armour orders was even more uncertain. Charles Ellis reported in October 1919 that 'it was a great misfortune that orders for armour had not been forthcoming, especially as the armour department was a very big one.'[80] By 1920 the company had 'no further use for the armour department' and had placed the plant at the disposal of the government should they require it for future armour production.[81]

An examination of the orders received for armour at Brown between 1915 and 1924 demonstrates the uncertainty of demand from the Admiralty. The company received an order for 3,500 tons of armour in late 1922 'which

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[75] A. Grant, *Steel and Ships: The History of John Brown's* (London, Michael Joseph, 1950), p.69.
[76] *The Times*, 30 June 1926.
[77] *The Times*, 30 June 1915.
[78] SA, X308/1/2/1/3/12, Brown's Managing Directors Report, 3 August 1916.
[79] SA, X308/1/2/1/3/13, Brown's Managing Directors Report, 1 March 1917.
[80] *The Times*, 1 October 1919.
[81] *The Times,* 30 June 1920.

would much improve operations during the [new] year'[82] However, this was the only order of any significance at Brown during the entire period, slumping to just 67 tons of armour ordered during 1924. Three years before, the company had proposed a plant capable of a minimum production of 7,000 tons a year. The peak of production for the armour plant would be between 1924 and 1925, though this small increase did little to alleviate the general decline of armour production (See Table 6.5). In September 1925 at Brown all of their armour treatment facilities had been shut down for the month, with little further armour work available.[83] There would be scarce armour for the rest of the decade.

Table 6.4: Summary of Brown's Armour Orders 1915-1924

Year	Total Armour Orders (£)	Largest Month Total (£)	Average Monthly Total (£)	Number Of Months With Orders Over £10,000
1915	352,887	217,511	29,407	3
1916	5,407	4,212	451	0
1917	188,658	108,480	15,722	4
1918	80,829	61,944	6,736	2
1919	25,175	14,825	2,098	1
1920	120,196	86,273	10,016	3
1921	51,852	26,980	4,321	2
1922	570,463	565,135	47,539	1
1923	53,386	47,626	4,449	1
1924	67	67	6	0

Source: SA, Brown's Managing Directors Reports 1915-1925

At the end of the Great War there were also some issues with the prices paid for armour. The figures provided for 1918-1919 and 1919-1920 were misleading, as in the monthly managing directors reports at Brown at the end of the company's financial year in March 1919 the decision was made not to invoice any armour orders to gain a better price on their production (See Table 6.5). Discussions took place in early 1919 with the admiralty regarding the prices paid for armour plates, to be retrospective over 1917 and 1918.[84]

[82] SA, X308/1/4/1/1/4, Brown's Works Committee Meeting Minutes, 29 January 1923.
[83] SA, X308/1/4/1/1/4, Brown's Works Committee Meeting Minutes, 29 September 1925.
[84] SA, X308/1/4/1/1/2, Brown's Works Committee Meeting Minutes, 28 January 1919.

Consequently, the figures for 1919-1920 represent two years output, a figure of £230,000 proposed for 1918-1919 in the records.[85] Brown were certainly looking for the best return on what they had produced, their chairman having already predicted a difficult time to come.

Table 6.5: Brown's Armour Sales and Production 1915-1930

Year	Total Armour Sales (£,000s)	Tons of Armour Produced	Average Price per ton
1915-1916	375	3,594	104
1916-1917	570	5,859	97
1917-1918	44	543	81
1918-1919	0	0	-
1919-1920	282	2,190	129
1920-1921	71	348	204
1921-1922	56	283	198
1922-1923	115	841	137
1923-1924	65	477	136
1924-1925	257	1,836	140
1925-1926	437	2,334	187
1926-1927	81	478	169
1927-1928	88	466	189
1928-1929	43	162	265
1929-1930	1	3	333

Source: SA, Firth-Brown Armaments Output Records, 1915-1945.

By 1930, the gloomy trading situation for the armourers was publicly commented on by Brown's chairman Baron Aberconway, who noted that:

> The consequences of all this have been felt quite keenly at our steel works in Sheffield owing to the diminution of orders for armour plate, gun forgings, and all the other high-class steel forgings and castings that were required for warships and big passenger liners, and their machinery and equipment. The quantity of armour required in recent years has been very small, and last year less than 50 tons were ordered by the Admiralty. It is obvious that this costly and most efficient plant can only be said to have value so far as it can produce work, but if you are faced

[85] SA, X308/1/2/1/3/15, Brown's Managing Directors Reports, 1919.

with an almost total cessation of orders you may consider this value to be comparatively small.[86]

Not that Brown were alone in suffering from a lack of armour orders, Cammell's business also declined and dividends were passed from 1923 (See Table 6.6).

Table 6.6: Cammell's Sheffield Works (Cyclops, Grimesthorpe, Penistone) Invoiced Output, Profit and Dividends 1914-1928

	Sheffield Works (£,000s)		All Cammell Business	
	Commercial (Percentage)	Armaments (Percentage)	Profit or Loss (£)	Ordinary Dividend (%)
1914	1,197 (64)	669 (36)	237,829	7½
1915	1,686 (68)	793 (32)	303,841	10
1916	2,627 (70)	1,117 (30)	321,372	10
1917	2,901 (76)	902 (24)	308,122	10
1918	2,936 (75)	966 (25)	282,094	10
1919	2,724 (88)	365 (12)	303,005	10
1920	3,606 (91)	340 (9)	260,632	7½
1921	2,427 (98)	61 (2)	170,487	5
1922	1,187 (90)	135 (10)	145,906	5
1923	1,748 (99)	24 (1)	70,053	Nil
1924	1,621 (92)	138 (8)	70,894	Nil
1925	1,371 (73)	495 (27)	-36,381	Nil
1926	916 (81)	216 (19)	-73,575	Nil
1927	1,633 (93)	126 (7)	-112,046	Nil
1928	1,421 (96)	60 (4)	-80,694	Nil

Source: WA, ZCL/5/43, Cammell Laird Board Meeting Minute Book No.10; ZCL/5/44, Cammell Laird Board Meeting Minute Book No.11

While Brown remained in profit, Cammell began making losses in 1925. To mitigate their issues, £300,000 was transferred from company reserves between 1925 and 1928, entirely eliminating what had been put aside from Great War profits.[87] Though Cammell's commercial output was greater than Brown, their armour orders also diminished following the Great War. The company approached the Admiralty regarding the future use of their armour

[86] *The Times*, 10 June 1930.
[87] WA, ZCL/5/44, Cammell Laird Board Meeting Minute Book No.11, 23 March 1926, 22 March 1927, 1 May 1928, 10 April 1929.

department after the stoppage of orders in early 1919. It was recorded that 'if the department is to be kept open for foreseeable future work the Admiralty should pay the expense or take the cost into account in the price of any orders for armour plate.'[88] In 1920 Hichens highlighted the poor trading conditions for the armaments companies, noting that 'it is unlikely that the armament firms will find any outlet for their special experience in the near future.'[89] He went on to note that 'We have been manufacturers of armour in Sheffield since 1863, and the costly equipment of our armour department is useless for any other purpose…If we cease to be manufacturers of armour we must scrap the whole of this plant and start afresh.'[90] Even when Cammell secured the order for HMS Rodney in 1922, Hichens remarked to the company OGM the next year 'I think you will wish me to say something about the battleship order we were fortunate – or unfortunate – enough to secure last November,' going on to suggest the work was worth having at a certain price, and it would boost the fortunes of their Birkenhead shipyard.[91] Armour production, and consequently its profitability, had been stifled at the end of the conflict, production dropping to just hundreds rather than thousands of tons per year, revived only with production for HMS Rodney (See Table 6.7) Once those orders for armour were completed, the prospects for future orders were depleted. From May to December 1926 Cammell's works in Sheffield and Penistone were entirely shut down.[92] The poor results for 1927 were blamed on an absence of armour orders, suggesting that despite plans for a broadening of trade for the company before the Great War, Cammell were still reliant on armour for their financial vitality.[93] The company could not fall back on other armaments products either, their shell shops closing in 1921 and converted to the production of small forgings. While the plant was heavily used in the Great War (See Table 6.8), after the conflict the decision was made to discontinue projectile production. Overall, in the wake of the Washington Treaty, the business of the two Sheffield armour producers collapsed, causing both Brown and Cammell to pass their dividends over

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[88] WA, ZCL/5/44, Cammell Laird Minute Book No.11, 27 March 1919, p.7.
[89] *Journal of Commerce*, 24 March 1920.
[90] *Journal of Commerce*, 24 March 1920.
[91] *Journal of Commerce*, 11 April 1923.
[92] WA, ZCL/5/44, Cammell Laird Board Meeting Minute Book No.11, 22 March 1927.
[93] WA, ZCL/5/44, Cammell Laird Board Meeting Minute Book No.11, 1 May 1928; *Journal of Commerce*, 2 May 1928.

several years. With projectiles, the fortunes were similar with declining profits at both Firth and Hadfields by 1930.

Table 6.7: Cammell's Production and Profits on Armour Sales at Cyclops Works West Forge 1914-1928

Year	Armour Sales (£,000s)	Tons Produced	Armour Profit (Loss) (£,000s)	Rate of Profit (Loss) (%)
1914	606	7412	173	29
1915	571	6262	213	37
1916	238	2231	(47)	(20)
1917	230	1957	36	16
1918	258	2394	(5)	(2)
1919	174	230	(21)	(12)
1920	123	128	(30)	(24)
1921	38	118	(27)	(71)
1922	135	746	14	10
1923	24	141	1	3
1924	138	744	88	64
1925	495	3003	114	23
1926	216	1192	43	20
1927	126	727	4	3
1928	60	137	-	-

Source: SA, ESC Box 192, Cammell's Sheffield Plant Sales and Details 1911-1927

Table 6.8: Cammell's Production and Profits on Shell Sales at Grimesthorpe Works 1914-1921

Year	Shell Sales (£,000s)	Number Produced	Shell Profit (£,000s)	Rate of Profit (%)
1914	63	23,350	6	9
1915	222	163,827	4	2
1916	879	751,099	25	3
1917	72	404,074	6	1
1918	708	374,634	32	5
1919	191	78,184	58	31
1920	217	1,542	79	36
1921	23	0	23	100

Source: SA, ESC Box 192, Cammell's Sheffield Plant Sales and Details 1911-1927

Table 6.9: Firth's Sales, Profit and Dividends 1914-1930				
	Total Sales to 1918, Commercial only 1919-30 (£,000) (Percentage)	**Shell Deliveries (£,000s) (Percentage)**	**Profit (£)**	**Ordinary Dividend (%)**
1914	1,192	*No data*	339,246	25
1915	2,601	*No data*	265,639	25
1916	4,916	*No data*	401,266	25
1917	4,733	*No data*	206,659	20
1918	4,853	*No data*	178,650	15
1919	1,898 (80)	469 (20)	179,236	7½
1920	*No data*	158 (-)	157,507	6¼
1921	946 (90)	100 (10)	*No data*	5
1922	*No data*	161 (-)	42,872	5
1923	922 (84)	180 (16)	8,750	Nil
1924	1,008 (87)	152 (13)	79,980	Nil
1925	1,149 (97)	33 (3)	70,299	Nil
1926	966 (87)	140 (13)	27,818	Nil
1927	1,212 (84)	225 (16)	122,000	3¾
1928	1,296 (85)	227 (15)	133,214	5
1929	1,447 (90)	169 (10)	166,090	6½
1930	1,217 (94)	72 (6)	27,652	Nil

Source: SA, Firth Records

An examination of Firth's business performance before and after the Great War also highlights the difficult trading environment (See Table 6.9). When several contracts were cancelled in November 1918, 95% of Firth's annual production had been for the war effort.[94] While incomplete data is available, the drastic decline in the output of the company in the early 1920s is apparent. In October 1920, Firth's shell shops were shut down due to a lack of orders.[95] Conditions changed and by the end of 1921 the company had £200,000 of shell orders on hand from the Government, but the infrequency of

[94] SA, X308/1/2/1/4/13, Firth's Report to Brown's Board, 28 November 1918.
[95] SA, X308/1/2/1/4/15, Firth's Report to Brown's Board, 28 October 1920.

demand had an effect on their profitability.[96] In 1923, the dividend was passed for the first time, the downturn in their fortunes exacerbated by the difficult trading environment and a lack of government orders. Their ordnance output for 1925 had fallen to just 3% of their total deliveries for the year. Unlike their contemporaries in Brown and Cammell the company was able to resurrect their fortunes in the late 1920s thanks to a brief resurgence of demand for projectiles, but by 1930 demand had once again disappeared. Their ordnance output shrunk, and with a lack of commercial work to take up the shortfall the dividend was passed once again.

Table 6.10: Hadfields' Invoiced Output, Profits and Dividends 1915-1930

	Commercial (£,000s) (Percentage)	Ordnance (£,000s) (Percentage)	Profit (£)	Ordinary dividend (%)
1915	816 (31)	1,811 (69)	265,403	25
1916	1,359 (27)	3,594 (73)	252,166	30
1917	1,260 (22)	4,443 (78)	257,509	30
1918	1,798 (34)	3,535 (66)	202,895	30
1919	1,623 (48)	1,768 (52)	203,154	10
1920	2,354 (75)	803 (25)	107,856	5
1921	2,097 (79)	567 (21)	158,157	5
1922	1,348 (66)	684 (34)	187,250	5
1923	1,555 (79)	403 (21)	106,510	4
1924	1,682 (89)	200 (11)	80,621	2½
1925	1,549 (86)	253 (14)	117,660	3
1926	1,372 (84)	263 (16)	68,875	2½
1927	1,702 (79)	454 (21)	187,223	5
1928	1,585 (76)	497 (24)	112,053	2½
1929	1,593 (83)	336 (17)	112,992	2½
1930	1,302 (89)	162 (11)	42,995	Nil

Source: Hadfields Box 63, Hadfields Invoiced Output 1910-1935, Volume 7 and Volume 8.

More data is available for Hadfields across the period, further demonstrating the drastic change in fortunes for the armament companies once the War was over (See Table 6.10). Ordnance output had been between half

[96] SA, X308/1/2/1/4/16, Firth's Report to Brown's Board, 22 December 1921.

and three quarters of Hadfields' annual output through to the end of 1919, after which demand declined into the 1920s. Armour piercing projectiles, the pinnacle of Hadfields' technological capabilities, had their greatest value of orders in 1915, after which demand declined for the company (See Table 6.11). After the conflict, the total shell orders at Hadfields and Firth would never reach these highs again.

Table 6.11: Hadfields' Armour Piercing Projectile Orders 1912-1917

Year	Value (£,000s)
1912	143
1913	260
1914	1,032
1915	2,230
1916	501
1917	434

Source: SA, Hadfields Box 114, Hadfields Armour Piercing Projectile Orders 1905-1917

Table 6.12: Summary of Projectile Orders to Hadfields and Firth 1920-30

Year	Hadfields Navy Orders	Hadfields Army Orders	Hadfields Total British Government Orders	Firth Total British Government Orders
1920	153	93	246	151
1921	348	0	348	212
1922	123	0	123	53
1923	254	0	254	143
1924	206	24	230	140
1925	236	16	252	142
1926	321	5	326	177
1927	380	0	380	201
1928	283	2	285	121
1929	98	6	104	39
1930	113	0	113	37

Source: Calculated from Hadfields Projectile Order Books No.4 and No.5.; Firth Armaments Production Records 1914-1939.

By examining the British Government's projectile orders from 1920 to 1930 (See Table 6.12), it is apparent that the main home buyer for Hadfields was the Navy, with Army orders small after 1920 as had been the case before the Great War. While figures for Firth are not available for each service, the smaller output of the company is apparent as outlined in their joint agreement with the Admiralty for supply from 1922. While somewhat more consistent than armour orders, the Washington Treaty still had a negative effect on the rate of production at each company. In 1931, Hadfield drew attention to the continued depression in trade, adding that 'A further handicap has been imposed upon some of our special lines of work by the general policy of Naval Disarmament.'[97]

Other efforts to profit from armaments technology were utilised in the 1920s to varying levels of success. With international subsidiaries the two projectile manufacturers had different approaches to their business activities. Firth's Riga works were evacuated in 1916 due to the advance of the German army and never reopened.[98] In the same year, the company unsuccessfully attempted to sell their holding in the Washington Steel and Ordnance Company.[99] The Washington Company was voluntarily liquidated 'owing to the uncertain future of American Government projectile needs' in 1922 after the Washington Conference, and was ultimately sold to the US Government in 1930.[100] Firth were clearly looking to reduce their international business, while Hadfields was looking to extend theirs after licensing their projectile production methods to Hadfield-Penfield. Formerly known as the American Clay Machinery Company based in Ohio, in 1919 the company acquired the sole rights to the entire Hadfield System of armaments production in the US, and changed their name to reflect this new direction.[101] An initial US Navy order for 3,500 16 inch AP projectiles was agreed to be manufactured in Sheffield, with final assembly in Ohio. In 1920 and 1921 Hadfields received orders for all of the shell bodies, to be supplied in a hardened and rough machined form, along with the finished caps for all the shell. With a total order value of £378,000 ($1,617,000), these orders helped to maintain Hadfields' large calibre shell plant in operation after the Great War. After final assembly, Hadfield-Penfield sold the projectiles to the

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97 SA, Hadfields Volume 8, Ordinary General Meeting Report 1930, 9 April 1931, pp.40-42.
98 SA, X306/1/2/2/1/1, Firth's General Meeting Minute Book No.1, 9 December 1916, p.232.
99 SA, X308/1/2/1/4/11, Firth's Report to Brown's Board, 1 June 1916, 3 August 1916.
100 SA, X306/1/2/2/1/1, Firth's General Meeting Minute Book No.1, 11 April 1922, p.276; X308/1/2/1/4/25, Firth's Report to Brown's Board, 26 July 1930.
101 SA, Hadfields Box 7, The Hadfields System in the USA, 1922, p.2.

US Navy for $3,288,000.[102] After years of sustaining losses and no new orders for projectiles materialising, Hadfield-Penfield ceased production in 1927.[103] The lack of demand for war materials also extended to the international business of the Sheffield armourers.

Foreign orders, a key part of the armaments business before the Great War and one of the most utilised methods of defending against the uncertainty of British orders, predominantly failed to materialise in the 1920s. Government consent was required for all foreign sales of armaments from 1921, though with a lack of home orders no requests from the Sheffield companies were rejected.[104] The most successful in the international field during and after the Great War was Hadfields, building on previous productive links developed before the conflict. In 1916, the company took on a large order for 5,000 14 inch AP projectiles for the US Navy, later described as 'a feat not without value as evidence of the resources of this country' during wartime[105] The order had caused some controversy at the Ministry of Munitions regarding the use of the same plant for British shell requirements and the large quantity of steel required, though Hadfields were ultimately allowed to proceed with the order.[106]

The War interrupted Hadfields' production for the Imperial Japanese Navy (IJN), though permission was received from the Government to supply a small number of 12 inch Heclon projectiles designed for oblique attack in October 1916.[107] In 1919 Hadfields restarted supplying the IJN, initially manufacturing projectiles ordered and suspended in 1914 and supplemented with two orders placed in 1920 and 1921. With the decreasing demand for AP projectiles in Britain, in 1923 Hadfields sought a new guaranteed supply agreement with the IJN. After a long process of negotiation a new contract was signed in 1924 worth £350,000 for AP projectiles capable of oblique attack, averaging £50,000 per year until 1930. Hadfields also granted a licence to the IJN for the use of all of their patents in Japan for AP projectiles, and for any new

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[102] SA, Hadfields Box 145, Secretary to RAH, 4 February 1927.
[103] On Hadfield-Penfield, see G. Tweedale, *Sheffield Steel and America: A Century of Commercial and Technological Interdependence 1830-1930* (Cambridge, Cambridge University Press, 1987), pp.121-126; and G. Tweedale, 'Transatlantic Specialty Steels: Sheffield High-Grade Steel Firms and the USA 1860-1940' in G. Jones, *British Multinationals: Origins, Management and Performance* (Aldershot, Gower Publishing, 1986), p.88.
[104] Davenport-Hines, Marketing, p.173.
[105] TNA, T181/69, Hadfields Evidence to Royal Commission on Private Manufacture of Armaments, 1936.
[106] TNA, MUN 4/3188, Papers on Hadfields US Shell Tender 1916-1917.
[107] SA, Hadfields Box 58, Correspondence related to Japanese Shell, 17 October 1916.

patents granted during the agreement.[108] Somewhat reluctantly, Hadfields also agreed to the training of a limited number of Japanese students in the manufacture of AP projectiles at their works in Sheffield, after which they would be employed at Kure Arsenal in Japan, where a projectile manufacture had been established in 1911 using Hadfields' licences. Writing to the Admiralty on the new agreement, Hadfields' director Augustus Clerke remarked that 'we were reluctant to accept such a condition in our Contract, but during the long course of negotiation became convinced that under no other condition could we obtain the work which is so badly required.'[109] Summing up their position Clerke wrote:

> You are already aware of the difficulty which we are experiencing in maintaining the efficiency of our plant under your present reduced requirements, and that some additional work is essential in order to maintain the technical skill of our employees.[110]

The Admiralty permitted the signing of the agreement, as it reduced their burden to provide Hadfields with orders to keep their large calibre plant operational. By 1930, Hadfields had supplied £356,000 of 14 inch AP projectiles, including the supply of unfinished shell for final assembly at the Kure Arsenal in 1929 and 1930 (See Table 6.13).

Table 6.13: Hadfields' Imperial Japanese Navy Orders 1920-1930

Year	Value
1920	£36,192
1921	£62,750
1924	£49,950
1925	£49,950
1926	£47,250
1927	£47,250
1928	£53,176
1929	£50,700
1930	£57,714

Source: Hadfields Projectile Order Books

[108] SA, Hadfields Box 66, Hadfields-Imperial Japanese Navy Agreement, 1924.
[109] SA, Hadfields Box 66, A.B.H. Clerke to The Director of Naval Ordnance, 26 June 1924.
[110] SA, Hadfields Box 66, A.B.H. Clerke to The Director of Naval Ordnance, 26 June 1924.

In comparison to Hadfields, Firth fared worse with international orders. The company undertook some shell trials in Italy during 1926, but no major orders were placed with the company.[111] The only orders received were for a total of 24 shells in 1927.[112] In 1921 Hadfields and Firth came to a market and royalty sharing agreement for foreign sales. For any orders outside of the British Dominions and the USA, the company which received the order would pay the other 10% of the total invoiced price, and each agreed not to tender in their established markets, Hadfields with Japan and Firth with Italy.[113] This was later reduced to 5% in 1924, after which Hadfield wrote to his fellow director Augustus Clerke that

> Personally I have always thought that it would have been fairer to say that Hadfields should be entirely free for Japan, and that Firths should be entirely free for Italy, that is, as regards making profit by executing orders…in either of those Countries…why not let us say to them “You can be free for Italy and we can be free for Japan without payments on either side.”[114]

With scarce orders from Italy for Firth, Hadfield saw the agreement as favouring their collaborator rather than being remunerative for them. From 1923 the two companies also collaborated on tenders for orders from Brazil and Argentina in an effort to remain competitive against the expanding American armaments industry. In writing to Hadfield on the matter, fellow director Peter Boswell Brown remarked that ‘without such a combination it would appear that our American competitors, assisted by the influence of their Government, are certain to obtain what few orders may be placed.’[115] Only one unsuccessful tender was submitted in March 1924 for 800-1,000 12 inch practice projectiles for the Brazilian Navy.[116]

With armour orders, Cammell’s only warship building program of the 1920s was HMS Rodney, the company recording no foreign orders at all. A tender for Chilean submarines in 1927 failed to bring orders to the company.[117] Cammell also arranged with a group called ‘The Pioneer’ in 1919 to represent

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[111] SA, X308/1/2/1/4/21, Firth’s Report to Brown’s Board, 28 July 1926, 27 September 1926.
[112] SA, X306/1/2/3/2/281, Firth’s Directors Meeting Agendas and Papers, 26 April 1927.
[113] SA, Hadfields Box 64, P.B. Brown to Robert Abbott Hadfield, 18 September 1923.
[114] SA, Hadfields Box 64, Robert Abbott Hadfield to A.B.H. Clerke, 18 February 1924.
[115] SA, Hadfields Box 64, Robert Abbott Hadfield to A.B.H. Clerke, 18 February 1924.
[116] SA, Hadfields Box 64, Tender For Practice Projectiles by Firths and Hadfields, March 1924.
[117] WA, ZCL/5/266/17, Admiralty General Correspondence File, 16 September 1927.

the company in the 'Kingdom of the Serbs, Croats, and Slavenes' to sell warships and submarines, which generated no orders.[118] Eastern Europe looked to be an outlet for armaments capacity in the 1920s after the formation of a number of new nation states at the conclusion of the Great War, though Vickers' experiences in Romania demonstrate the difficulties of obtaining orders from these new customers.[119] Elsewhere, collaboration remained between Vickers and Armstrong, who came to a market sharing agreement for orders in South America, China, Japan, Spain, Portugal, Greece and Turkey in 1924.[120] During 1927, the armaments business of both companies merged to form Vickers-Armstrongs, with Vickers continuing as the parent company of the new group.[121]

In May 1928 enquiries were received at Hadfields and Firth for the production of finished 14 inch and 11 inch projectiles for the Chilean Navy. Before the Great War both companies had maintained business connections to produce finished projectiles filled with explosives and fitted with fuzes, neither could complete the order to the required specifications without some outside collaboration. Agreeing to work together to produce the projectile bodies, Hadfields and Firth called a meeting with Vickers-Armstrongs to discuss the possibility of working as a British group for the enquiry. At the meeting Hadfields and Firth proposed to manufacture the empty projectiles, after which Vickers-Armstrongs would fill them, add their fuzes, and undertake any required testing. Hadfields and Firth also suggested that Vickers-Armstrong be the main contractor for any future orders due to their increased name value in the international market. The arrangement was agreed to, with the normal prices charged for projectiles by Hadfields and Firth discounted by 15 per cent to Vickers-Armstrongs to provide them with extra profit on the order. At the end of the meeting it was suggested to extend the arrangement to all future foreign orders, thus creating 'a powerful combination with resources exceeding those of any Continental or USA firms.'[122] The arrangement for Chile also led to the

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[118] WA, ZCL/21/1/10, Cammell's Patent File 15j, 23 October 1919.
[119] R.P.T. Davenport-Hines, 'Vickers Balkan Conscience: Aspects of Anglo-Romanian Armaments 1918-39', in R.P.T. Davenport-Hines (Eds.), *Business in the Age of Depression and War* (London, Frank Cass, 1990), pp.253-285.
[120] Davenport-Hines, *Disarmament*, p.72.
[121] For a discussion of the merger see Warren, *Armstrongs*, Chapter 29: The Reconstruction of Armstrongs and the Rationalisation of the Heavy Armament Business in 1927 and 1928.
[122] SA, X306/1/2/3/2/296, Notes of Meeting of Vickers-Armstrongs, Firths and Hadfields, 18 May 1928.

three companies formalising an agreement with the British Government to provide the required secrecy when quoting for any future foreign orders.[123] The companies knew their future bargaining power with the British Government was greater as a group than if any of them left the industry. Group action with foreign orders such as the one proposed for Chile demonstrates how competition among armaments producers had disappeared in the international market in the 1920s, collaborative defensive measures required by the members of the industry in a bid to keep it alive against the backdrop of scarce orders at home and increasing opposition from abroad. The business of the companies involved was only one facet of the decline of the industry in the 1920s, the management and structure of the armaments business also had a key role in its downturn.

Stagnation and Disintegration: Management and Industry Structure 1914-1930

After the Washington Naval Treaty in 1921, with the market for armaments in Britain declining and with it any need to continue to maintain close and special relationships with the supply ministries washed away, the management at each company in the Sheffield armaments industry stagnated. Each board of directors aged along with the companies they managed. Dominated by pre-war appointments, each retained older mentalities about what the armaments industry was, clinging to the belief that the vitality the industry enjoyed before the Great War would return. It has been claimed that after the War the armaments industry fell back on what they knew before the conflict, concentrating on close links with the admiralty and naval production.[124] This may suggest that the armaments companies brought in new external appointments to further build their links with the supply ministries, but as will be demonstrated this was not the case.

At Hadfields, Robert Abbott Hadfield remained chairman of the company, with management required to adapt to his personal style of leadership. During the War, Hadfield relocated to his London home at 22 Carlton House Terrace, which became the temporary head office of the company for the remainder of the conflict with all issues related to government orders passed though the

[123] TNA, T181/109, Agreements between Service Departments and Arms Firms, prepared for the Royal Commission on the Private Trade in Armaments, 1936.
[124] Packard, *Whitehall,* p.43.

house. Fellow directors Alexander Jack, Peter Brown and Augustus Clerke all moved to London to assist with the running of the company as all of their board meetings took place at the property, and up to four or five daily directors' conferences.[125] With Hadfields' board of directors, there were a number of appointments during the conflict, and once two of the oldest serving directors retired in 1920 the final addition of the period was made in 1921 (See Table 6.14). During the 1920s the board shrank in size due to deaths, yet these were not replaced. Before the War, Hadfields had expanded their directorship with a number of ex-government and military members, rapidly replacing any which retired or died. With limited need to retain close connections with the supply ministries, this approach was not replicated in the 1920s.

Table 6.14: Hadfields' Directors 1915-1930, and directors who continued 1930

	Appointed to Board	Office	Left Board
Robert Abbott Hadfield	1888	Chairman and managing director from 1888	Continued
Alexander G.M. Jack	1897	Director, MD from 1905	Retired 1920
Henry Cooper	1905	Director	Retired 1920
Lord Claude John Hamilton	1909	Director	Died 1925
Peter Boswell Brown	1910	Director	Continued
Major Augustus Basil Holt Clerke	1913	Director	Continued
Issiah Milne	1914	Director – head metallurgist	Died 1926
J.P. Crosbie	1915	Director	Continued
W.B. Pickering	1915	Director	Continued
J.T. Middleham	1916	Director and Secretary	Died 1922
Commander E.H.M. Nicholson	1917	Director	Continued
W.J. Dawson	1919	Director	Continued
Henry B. Sandford	1921	Director	Died 1930

Source: SA, Hadfields Annual Reports 1888-1930.

[125] SA, Hadfields Box 57, Statement as to the War Work Done at Sir Robert Hadfield's House, 22 Carlton House Terrace.

Table 6.15: Brown's Directors 1915-1930, and directors who continued 1930

	Appointed to Board	Office	Left Board
Baron Aberconway	1883	Deputy chairman from 1897, chairman from 1906	Continued
Charles Edward Ellis	1884 (1st) 1919 (2nd)	MD from 1892-1915, and 1919-1928, with Ministry of Munitions 1915-1919	1915 (1st) Continued (2nd)
Captain Tolmie John Tresidder	1891	Director	Retired 1930
L-Col J.G.S. Davies	1896	Director	Retired 1922
Bernard A. Firth	1903	Deputy chairman from 1906	Died 1929
John Sampson	1904	Director	Died 1925
William H. Ellis	1906	Managing director from 1919	Continued
Thomas Bell	1907 (1st) 1919 (2nd)	Managing director from 1920, with Admiralty 1917-1919	1917 (1st) Continued (2nd)
Lord Pirrie	1915	Director	Died 1924
Alan John Grant	1919	Managing director from 1928	Continued
Henry D. McLaren	1925	Director	Continued
Captain T.E. Crease	1928	Director	Continued

Source: Grant, *Steel and Ships*

Brown's board demonstrates a similar pattern to Hadfields, with one new appointment during the conflict following the recruitment of their managing director Charles Ellis to the Ministry of Munitions in 1915 (See Table 6.15). After the War, one new appointment was made in Alan Grant who took over from Ellis as managing director in Sheffield. The retirement and death of a number of board members in the 1920s was not followed by their replacement, nor the addition of members with governmental links following the death of Lieutenant-Colonel Davis. A family appointment was made in 1925, Baron Aberconway's son Henry McLaren joining the board, followed by Captain Crease who had been employed by the company on armament matters since 1922. Consequently, Crease is the only appointment by any of the four companies examined to have prior military or governmental links during the 1920s. While this had been common before the Great War, with the limited demands for armaments after the conflict Crease is an exception.

Table 6.16: Firth's Directors 1915-1930, and directors who continued with Firth-Brown

	Appointed to Board	Office	Left Board
Bernard A. Firth	1888	MD from 1900, chairman from 1903	Died 1929
E. Willoughby Firth	1893	Director	Continued
James Rossiter Hoyle	1893	MD from 1903 to 1922	Died 1926
John Sampson	1899	Director	Died 1925
Charles E. Ellis	1903 (1st) 1919 (2nd)	Director, with Ministry of Munitions 1915-1919	1915 (1st) Continued (2nd)
Baron Aberconway	1903	Director	Continued
Frederick C. Fairholme	1909	Assistant MD from 1910, managing director from 1921	Continued
Major Harry Bland Strang	1909	Director	Resigned 1930
Edward Dixon	1921	Director	Continued
Percy William Fawcett	1922	Director	Continued
John Charles Bradley Firth	1927	Director	Continued
Allan John Grant	1930	Director	Continued
Henry D McLaren	1930	Director	Continued

Sources: SA, X306/1/2/2/1/1, Firth's General Meeting Minute Book. Note, Strange changed the spelling of his surname to Strang during the Great War

At Firth, management remained static during the Great War (See Table 6.16). An example from the conflict demonstrates the insularity of management in the industry. In 1915 Arthur Daulby Wedgwood, a director of Cammell until 1913, was appointed General Manager of Firth''s National Projectile Factory.[126] When Wedgewood resigned from the position due to ill health in 1916, Bernard Firth drew attention to 'the difficulty of appointing a stranger to the position' and after some discussion Frederick Fairholme took up the role.[127] Recruitment from within the industry was clearly the preference for the company. Two new appointments were made in the early 1920s, with an addition made after the death of two long-serving directors which fell back on older family links with the

[126] SA, X306/1/2/3/1/4, Firth's Directors Meeting Minute Book No.4, 31 August 1915, p.278.
[127] SA, X306/1/2/3/1/4, Firth's Directors Meeting Minute Book No.4, 28 March 1916, p.313.

enrolment of John Charles Bradley Firth. The two appointments in 1930 of members of Brown's board foreshadowed the merger between the two companies, as discussed below. Major Strang resigned from Firth's board in March 1930, but was retained by the company as a technical consultant with armaments work, paying him £500 per year.[128] Even with a decade of limited orders, Firth still saw themselves as an armament company, and aimed to retain the skilled connections they had developed over the previous decades, yet did not recruit any new directors with military or governmental links during the 1920s. Finally, Cammell too demonstrates a lack of change in their board of directors, the only new appointments in the 1920s to managing director positions for their three works in Birkenhead, Sheffield and Nottingham (their former National Projectile Factory, converted to produce rolling stock). Retirements and deaths reduced the size of the board, with long-time connections to the Government in Samuel Roberts MP and Major Handley not replaced (See Table 6.17).

The management of the Sheffield armaments industry corroborates Wilson's observation that continuity was a major feature of British business from 1914 through to the 1940s, as it had been from the 1870s to the start of the Great War, with attitudes and the practice of management changing very little.[129] The combined directorships of the four companies reflect this continuity. Up to 1928, the combined experience of the board of Cammell was 113 years, Hadfields 126 years, Firth 173 years, and at Brown a total of 200 years, with six directors having served over 35 years as a board member. E. Willoughby Firth (35 years), Tolmie John Tresidder (37 years), Bernard Firth (40 years at Firth), Charles Ellis (40 years at Brown, excluding time at the Ministry of Munitions), Robert Abbott Hadfield (40 years) and Baron Aberconway (45 years at Brown) reflect the stagnation of management and leadership in the armaments industry during the 1920s. At a time when new blood and ideas were needed, the companies stuck to what they knew best. If continuity was the common feature of management in the industry, conversely change in its structure characterised the post-Great War environment.

[128] SA, X306/1/2/3/1/6, Firth's Directors Meeting Minute Book No.6, 26 March 1930, p.337.
[129] J.F. Wilson, *British Business History, 1720-1994* (Manchester, Manchester University Press, 1995), p.176.

Table 6.17: Cammell's Directors 1915-1928, and directors who continued 1928

	Appointed to Board	Office	Left Board
Colonel William Sidebottom	1896	Deputy chairman from 1901, chairman 1904-5, 1909-10	Retired 1918
Samuel Roberts MP	1896	Director	Died 1926
Robert Whitehead	1901	Director	Director at time of ESC Merger
Herbert Edward Wilson	1904	Director	Retired 1924
Alexander Gracie	1905	Director	Director at time of ESC Merger
Major Arthur Handley	1908	Director	Died 1927
Henry Westlake	1908	Director	Resigned 1915
William Lionel Hichens	1911	Chairman from 1911	Director at time of ESC Merger
George John Carter	1912	Managing director at Birkenhead from 1912	Director at time of ESC Merger
James McNeil Allan	1913	Managing director at Sheffield and Penistone from 1913	Retired 1928
George Turner	1919	Director	Retired 1922
Robert Stuart Johnson	1920	Managing director at Birkenhead from 1922	Director at time of ESC Merger
Arthur Stowey Bailey	1921	Managing director at Nottingham from 1922	Director at time of ESC Merger
Charles Lyall Mason	1928	Managing director at Sheffield from 1928	Director at time of ESC Merger

Sources: WA, ZCL/5/171, Cammell-Laird Register of Directors 1901-1913, ZCL/5/62, Cammell-Laird Register of Directors 1914-1924.

As highlighted in Chapter 4, the Coventry Ordnance Works (COW) was established as a defensive measure for the companies involved to counter uncertainty in their home market. Its establishment and ownership pattern with Brown, Cammell and shipbuilder Fairfield created a knowledge and risk sharing network with COW at its centre, the point at which communication for the group took place. Armaments orders to the company had drastically increased during the Great War, but its position in the post-War world was a cause of anxiety for those involved. Hichens had been appointed chairman of COW before the War, and as early as 1917 he foresaw future issues for the company. He suggested that COW:

> Was an Imperial asset as a national arsenal of the first importance, and he could not believe that the Government would adopt a policy of using it to the full in time of need and then throwing it away like a sucked orange…it was fair to say that our unpreparedness for the war had taught us a lesson, and that the maintenance of our military equipment would not be left in future to – he might almost say – private charity, for the Coventry Works were run at a heavy and continuous loss before the war.[130]

Hichens understood that there would be limited armaments work for some time to come after the end of the War, and suggested that 'an exclusively armament firm, like the Coventry Ordnance Works, would shrink to almost nothing or close down altogether unless it found some other outlet for its activities.'[131] Discussions regarding the post-war position of COW had occupied the Cammell's board before the end of the war, with the production of electrical goods a likely possibility.[132] Hichens made several requests to government departments regarding the future of COW. He finally gained a response from David Lloyd George in his role as Prime Minister in January 1919, who said that the works would not be required by the Government thereafter. In 1919, while discussing the COW Charles Ellis highlighted that he had 'always been one of those who believed that a war would be the ruin of armament companies, and he did not think he was very far wrong.'[133] At the end of 1918, COW became part of the newly formed English Electric Company. Tresidder and Carter, who represented Brown and Cammell on the COW board, resigned in December 1918.[134] The English Electric Company prospectus in 1919 listed as its directors Charles Ellis, Bernard Firth, Lionel Hichens, John Sampson and Alexander Gracie, and was financed with an initial share capital of £3.5million in £1 shares.[135] There were connections to armaments companies included as part of the new board, but the production of war materials was not on the agenda for the new company. The COW works closed in 1922 and went into voluntary liquidation in 1925.[136]

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130 *Sheffield Daily Independent*, 19 April 1917.
131 *Journal of Commerce*, 10 April 1919.
132 WA, ZCL/5/43, Cammell Laird Minute Book No.10, 6 November 1918, p.443.
133 *The Times*, 1 October 1919.
134 Warren, *Steel, Ships and Men*, p.180.
135 SA, X313/7/1/1. English Electric Prospectus, July 1919,
136 Warren, *Steel, Ships and Men*, p.180.

Before this closure, there had been a suggestion to keep COW in operation for foreign gun orders marketed by the Coventry Syndicate.[137] The Coventry Syndicate had been established in October 1913 to co-ordinate the efforts of Brown, Cammell, Fairfield and COW in the international market, under the guidance of managing director Captain T.E. Crease. A former Naval Assistant to Admiral Jackie Fisher, Crease was also appointed a local director of Cammell and COW and a special director of Brown in November 1919.[138] With a lack of government orders following the Great War, the Coventry Syndicate increased in importance and from 1919 the group searched for foreign markets. A representative was sent to Japan in December 1920 to work on sales of armour and shells, and in 1921 a test plate for the Dutch Navy had been ordered, manufactured from stock at Brown.[139] However, the transition of COW to the ownership of English Electric and the downturn in armaments demand affected their prospects. Fairfield resigned from the Coventry Syndicate in October 1919, and as a consequence of English Electric abandoning the manufacture of armaments the group was wound up in June 1921 having had their ability to sell finished guns stifled. At their final meeting ‘it was pointed out that one of the primary causes of the dissolution of the Syndicate is the action of the English Electric Company in regard to the sale of Scotstoun and the abandonment of armament manufacture generally.’[140] The COW’s Scotstoun works had been the only facility open to the group for the fitting of gun mountings to battleships. With the Coventry Syndicate wound up, Brown offered Crease employment as a special director for foreign work with Brown and Firth, and he became a director of the company in 1928.[141] With COW and the Coventry Syndicate closed, the armaments network constructed by the companies involved in the grouping was shattered, their previous collaborative defence against uncertainty in their home market disintegrated. Other connections built by the armaments industry before the Great War were also severed after the end of the conflict. Cammell looked to sell their 12,500 shares

[137] WA, ZCL/5/43, Cammell Laird Minute Book No.10, 8 January 1919, p.451.
[138] SA, X308/1/6/1/1. Thomas E. Crease to the Coventry Syndicate, 4 November 1919; Grant, *Steel and Ships*, p.71.
[139] SA, X308/1/2/1/10/1, Coventry Syndicate Meeting Minutes 13 April 1921; X308/1/4/1/1/3, Brown’s Works Committee Meeting Minutes, 27 September 1920.
[140] SA, X308/1/2/1/10/1, Coventry Syndicate Meeting Minutes, 13 April 1921.
[141] SA, X308/1/2/1/4/17, Firth’s Report to Brown’s Board, 31 August 1922.

in Fairfields in June 1919, relinquishing them two months later at £37 each.[142] In 1926, Vickers disposed of their 845,000 shares in Beardmore to Lady Invernairn for £75,000.[143] In the wake of these closures and sales, the only connection which remained was the one between Brown and Firth, which also experienced some strains during and after the conflict.

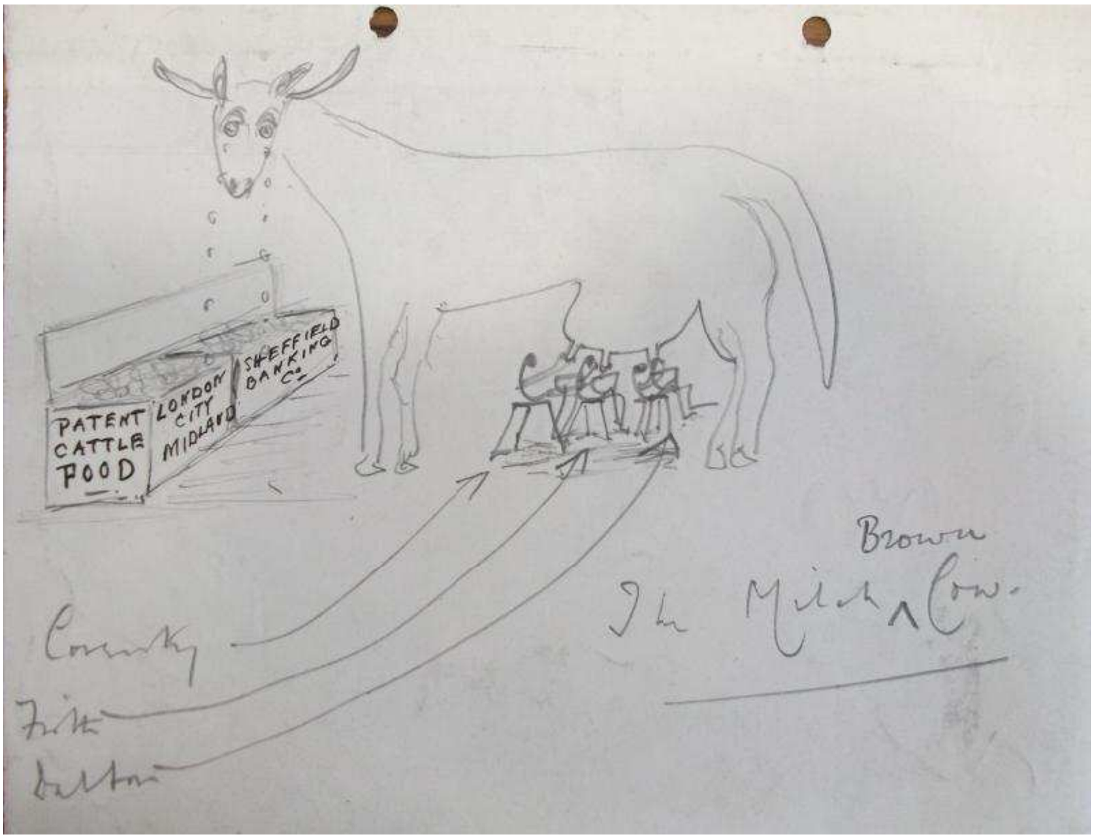

Figure 6.1: 'The Milk Brown Cow' from X308/1/2/1/4/11, Firth's Reports to Brown's Board, filed between reports for 1 June and 27 June 1916.

In 1916, an unknown director at Brown sketched a picture titled 'The Milk Brown Cow' which remains in a collection of reports Firth sent to Brown each month (See Figure 6.1). The image depicts a cow, presumed to represent the company, feeding from a trough labelled 'Patent Cattle Food' with the names of several banks listed with it. Beneath the cow are three milking stools, one labelled Firths, one Coventry, and one Dalton (Brown's colliery). Given their ownership of half the shares in COW, and 7/8ths of Firth, Brown clearly felt that their subsidiaries were excessively using them for financial assistance. This

[142] WA, ZCL/5/44, Cammell Laird Board Meeting Minute Book No.11, 4 June 1919, 29 August 1919.
[143] J.R. Hulme and M.S. Moss, *Beardmore: The History of a Scottish Industrial Giant* (London, Heinemann, 1979), p.198.

situation changed in 1917 when Firth agreed to loan Brown £100,000.[144] Only half was repaid by 1928, after which a further £100,000 was loaned to their parent company the following year.[145] The finances of the two companies had become increasingly intermingled since the Great War, and rationalisation of the two looked increasingly likely.[146]

After long discussions, in December 1930 the amalgamation of Firth and Brown was completed, Firth taking over all of the steel making capacity of Brown in Sheffield and Scunthorpe under the new name of Firth-Brown. John Brown remained a shipbuilding company, controlling the share capital of Firth-Brown.[147] This was not the first grouping among armaments companies in Sheffield. After incurring losses for several years, Cammell joined discussions regarding the amalgamation of their steel works with those of Vickers and Vickers-Armstrongs, and from 1929, Cammell became part of the English Steel Corporation.[148] Hichens spoke at length at Cammell's OGM in 1929 after the ESC amalgamation about the depressed state of the armaments industry and its effect on his company. His words deserve full repetition:

> The armour trade, which in pre-war days was our principal activity, has completely collapsed. In pre-war days our shipyard was seldom without either a battleship or one or two cruisers or several destroyers; to-day we have one submarine on the stocks and have just received an order for another. We used to consider our armour shops empty if we had not 6,000 tons or so of armour passing through them each year; to-day we have, perhaps, a couple of hundred tons. Our trade in big armour piercing shell is gone altogether, as has our trade in guns and gun-mountings which was carried on at the Coventry Ordnance Works. We were left with a wreck in a raging sea, and it is small wonder that some of

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144 SA, X308/1/2/1/4/12, Firth's Report to Brown's Board, 2 August 1917.

145 SA, X308/1/2/1/4/23, Firth's Report to Brown's Board, 25 May 1928; X308/1/2/1/4/24, Firth's Report to Brown's Board, 4 October 1929.

146 On rationalisation in British business, see Wilson, *British Business History*, Chapter 5: Rationalisation and Corporatism, 1914-1945.

147 Grant, *Steel and Ships*, pp.73-5; G. Tweedale, *Steel City: Entrepreneurship, Strategy and Technology in Sheffield 1743-1993* (Oxford, Clarendon Press, 1995), pp.257-8.

148 Warren, *Steel, Ships and Men*, Chapter 15: Amalgamation and Rationalisation: The Formation and Early Development of the ESC; Davenport-Hines, *Disarmament*, pp.157-162. The Bank of England was also involved in the ESC and Vickers-Armstrongs mergers. See S. Tolliday, *Business, Banking and Politics – The Case of British Steel 1918-1939* (Cambridge Mass, Harvard University Press, 1987), pp.193-7.

> the spars and rigging have been carried away. We are lucky to have escaped shipwreck.[149]

The 1920s had been a difficult decade for the Sheffield armaments industry, and as 1931 commenced its structure in the city had drastically changed. The five companies which produced arms had been reduced to three though mergers, the vertical links so characteristic of the Edwardian period replaced by horizontal combinations, with only Hadfields emerging unaffected. The depressed state of the industry would remain until the rearmament programme commenced in 1936.

Conclusion – The Sheffield Armaments Industry in 1930

If the Sheffield armaments industry had been at its zenith in 1914, it was at its nadir in 1930. Management of the industry had stagnated, the inter-company arrangements central to the industry before the Great War had been swept away, general profitability had been replaced by persistent losses, and any semblance of a special relationship with the industry had died once the Washington Naval Treaty had been signed. In its place, 'necessary relationships' took over, designed to protect capacity at a time when there were no orders. The industry in 1930 was a pale comparison to how it was in 1914 (See Figure 6.1). In Sheffield, the five companies had become three following mergers, with the former armour producers all leaving the city by name, retaining only ownership connections. Technology links, the core of the industry in the Edwardian period, had all lapsed and disappeared, the only remaining arrangement between Hadfields and Firth signed in 1917. The sole national links were with the government to protect capacity, and internationally all that remained was membership of the Steel Manufacturers Nickel Syndicate, no longer key to armaments production but to increasing manufacture of specialist alloy steels. Consequently, armaments were no longer central to the Sheffield steel industry in 1930.

The reduction in the number of companies also led to a reduction in the productive facilities available for armaments. The loss of capacity in the industry was regrettable to the Government, and 'it was the dispersal of research, development and production specialists within the companies, and the loss of

[149] *Journal of Commerce*, 24 April 1929.

their records and traditions, that caused the keenest anxiety to procurement officers.'[150] It was this skill, knowledge and expertise of the directors, managers, research staff and workers that the industry was built on. Collaboratively, they had made Sheffield the centre of world armaments production and technology, and created the knowledge base upon which the special steels of the 1920s would develop. By 1930, the industry was on its knees, never to return to its technological and productive glories.

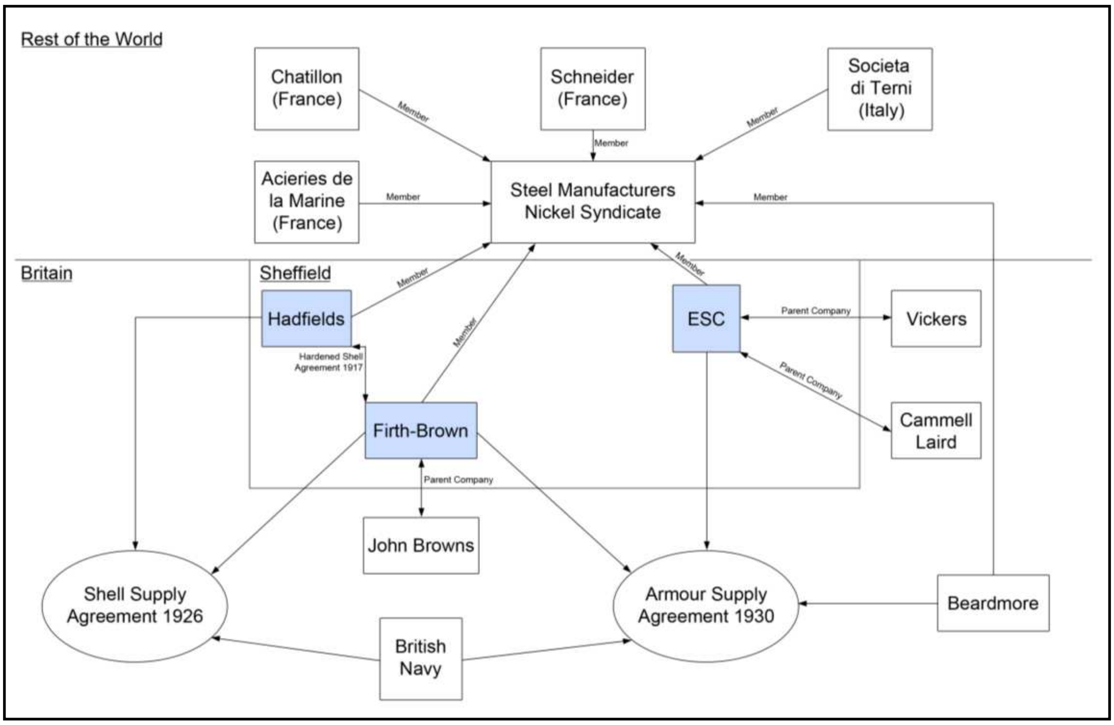

Figure 6.2: The Sheffield Armaments Industry in 1930

[150] Davenport-Hines, Marketing, p.153.

Conclusion

This study has explored the business and technology of the Sheffield armaments industry through the use of four in-depth case studies of Brown, Cammell, Firth and Hadfields, and provides revisions to our understanding of the armaments business in Sheffield, Britain and the wider world. Examining a longer period of time, exploring the development of armaments technology, placing the focus on companies other than Vickers and Armstrong, and moving the focus away from shipbuilding to steel, this conclusion provides an overview of the observations and revisions this study has made.

The Sheffield armaments industry provides an example of a sector which required the application of science, in this case metallurgy, for its continued technological vitality. From 1900 developments with projectiles and armour had reached the limits of rule of thumb methods, and required more scientific approaches for their advancement. Metallurgical knowledge and techniques, such as the role of specific elements in the manufacture of steel, forging and casting, were incorporated from off the shelf methods, while exploring new elements for alloy steels. These experiments were part of a long continuum in which armaments-based and commercial-based metallurgy had a reciprocal influential relationship, each drawing from the other when required. By the outbreak of the Great War, a wide range of compositions and treatments had been developed from refining the performance of projectiles and armour plate, with several research dead-ends reached in addition to successes. This provided a broad knowledge base for utilisation by the civilian metallurgical industry, some of which was derived from research dead-ends. One innovation before the war, stainless steel, demonstrated how armaments research could be rapidly utilised for civilian products. Furthermore, research and development in the armaments industry involved path-dependent technological evolution. Starting with several major innovations, bulk steel, forging and casting production techniques, the teams involved in armaments development utilised sub-innovations to refine their performance, a series of incremental improvements which individually were of little consequence but cumulatively created advanced armaments products. The continued success of a company to innovate in the industry was based on the maintenance of the same research team involved, the technological path dependence at each company idiosyncratic with the staff involved in the research laboratory. The development of armour piercing projectiles also highlights how different companies innovate in different ways, Hadfields and Firth utilising different major innovations for their research yet ultimately solving the same problems at almost the same time. Importantly, this research has made some key observations regarding the process of innovation at armaments companies. Considerations as to the typical inputs available to companies, the importance of path-dependent research, the role of knowledge, the opportunities for spin-off, and the connections to wider innovation were all highlighted as important aspects of armaments technological development.

From this study three key revisions to Trebilcock's notion of spin-off in the armaments industry can be presented. Firstly, it is possible to demonstrate that a two-way interaction between metallurgy and armaments occurred in the industry, armaments drawing on established methods and adding new experimental ideas, before passing down new knowledge to commercial industry. Secondly, the spin-off of knowledge was a key element of the spin-off paradigm, developed from both successes and research dead-ends in the industry. This knowledge was also maintained by the teams working in research laboratories, allowing for its swift utilisation for future armaments and commercial research. Finally, it has been shown that spin-off from armaments to commercial developments did occur between departments at armaments companies, with refinements to established products such as rock and ore crushing machinery possible. From the early 1900s, a mix of armaments-focused and commercially-focused research were driving product developments at the companies involved. As the data on armaments research is limited solely to patent records, it is only possible to speculate as to the full extent of metallurgical knowledge developed by armaments research and passed on to civilian industry.

In the course of armaments technical development, knowledge was an important factor and consequently resource to the research teams involved. From the investigations undertaken to refine the performance of armaments products, companies were able to create and retain knowledge related to both armaments and metallurgy within their research laboratories. In cases where this tacit knowledge became codified and part of patent records, this allowed for the licensing and transmission of technology. Reciprocal licensing arrangements, whereby any advances made were reported back to the original inventor by anyone using the technology, were central to the armaments industry's technological profile. This research has also uncovered the use of marketing materials for the sale of systems of armaments manufacture used by both Firth and Hadfields for projectiles. Nevertheless, patent records are problematic. They only uncover what has been written down, not the vast experimentation and potentially exponential knowledge retained by a research team and subsequently lost to history. For the receiver, a patent only informed them of how to produce a product, not why it was produced the way it was. In this regard, patents were useful for licensing and making a return on technology, while also being a defence against any new entrants to the market.

The use and transmission of knowledge highlights how Sheffield made important connections through licensing agreements to other companies in the sector across the world in an armaments-metallurgy-steel innovation system. In this regard, the connections between actors involved in armaments innovation are emphasized between the companies, technocrats, and universities connected to the industry. By demonstrating the evolution of the system over time, the research has highlighted how Sheffield remained at the centre of the world armaments industry, with technological, productive and supply agreements across the Globe from 1900 to 1930. The growth of the industry and its consolidation in 1914 was a high point, its decline in the 1920s demonstrating how many of these links disappeared by the end of the decade and armaments-focused metallurgy was replaced by metallurgy that focused on peacetime manufactures. More research is required into the evolution of the system in the 1920s, as it is unknown if the movement from armaments research to civilian metallurgical research was replicated in the links companies made to trade associations and with alloy steel licensing agreements.

The Great War was a turning point in the technical development of the industry. Metallurgical research and armaments research diverged, armaments seeking more practical refinements for their products while metallurgy inherited a vast pool of knowledge created from armaments developments. The effect of various elements on the performance of steel, treatment and production techniques were all utilised by research teams at the armaments companies to advance the special steel industry in Sheffield in the 1920s. Stain and heat resisting steels were central to their developments, and an analysis of the patent records of the companies involved demonstrated the influence armaments research had on their new designs and innovations. Nevertheless, when required armaments could still draw on metallurgy to continue to develop new products, as was demonstrated at the start of the 1930s. The metallurgical knowledge created, and its legacy with the development of stain and heat resisting steels, were key determinants of the evolution of the next generation of armaments products, including the aircraft and motor vehicles. In this regard, more research is needed to chart the evolution of the special steel industry and its links to these new war materials to find the true extent of the Sheffield armaments industry's technological legacy.

Putting Sheffield at the centre of an armaments-metallurgy-steel innovation system also advances the notion of industrial districts. Sheffield was the centre of the industry, and the small number of companies involved allows the advancement of a capsule network. As has been highlighted, the small membership led to collusive behaviour and unresponsiveness once the demands of the Great War were apparent in late 1914. However, by focusing on a capsule network with a small number of companies involved overlooked the rest of the Sheffield steel industry and the other links made between armaments and non-armaments companies in the city. Further investigation may reveal a greater number of connections between actors in the city involved with research and metallurgy, broadening the influence of the armaments sector in the wider steel industry.

By investigating the special relationships paradigm advanced by Trebilcock, the research has further explored the connections between the state and private industry and provides some key revisions to the work of Trebilcock, and Davenport-Hines. It has been advanced that prior to the Great War, there was a hierarchy of special relationships in the industry, with some companies seen as more favoured than others. This is replicated in the membership of each company's directorships, the guaranteed supply arrangements entered into, and the case of Cammell's dismissal from procurement lists. The extent to which hierarchies of special relationships are replicated in other sectors of the armaments business, such as small arms, cordite and shipbuilding, requires further investigation. The Great War changed the perception of special relationships, the hierarchy collapsing as all industrial capacity was required for the conflict. With the signing of the Washington Naval Treaty in 1921, the outlook for the industry looked bleak, the demand for armaments disappearing overnight. Against this backdrop, the government scrambled to retain capacity should they require any armaments products in the future. Signing agreements for both armour and projectiles to ensure companies retained their capacity, the notion of special relationships was washed away, and in its place a series of 'necessary relationships' to ensure the business did not disappear were implemented. Overall, before the Great War the armaments companies were able to fund their research and development activities in-house, the demand for armaments from their home governmental buyers meaning profits could be re-invested in the constant cycle of experimentation in the industry. After the War, this approach was ultimately unviable, the government forced to pay the companies in the industry to maintain their research and productive capabilities in place should demand arise again.

The exploration of special relationships also highlights the management of the industry and the need to recruit ex-military and governmental personnel to the directorships of each company. These directors brought with them important connections to the supply ministries and Whitehall, and in many cases technical information to supplement and advance the research of the company. The research has also highlighted the response of management to the uncertainty of the armaments market through the implementation of a number of defensive measures. The establishment of the Coventry Ordnance Works exemplifies this, a collaborative business venture designed to counter uncertainty in the market, and through the establishment of a director network, the sharing of both risks and knowledge. International business, both individually and collaboratively were also used to defend against uncertainty, maximise output and profits, and continue to employ and make a return from their works and research efforts. Prior to the Great War individual approaches to international markets were the most successful, yet in the 1920s collaboration was a more desirable approach due to increasing competition from overseas armaments producers.

Overall, management was highly entrepreneurial, seeking new ways to exploit markets for armaments, promoting their products to their home buyer, controlling knowledge about future demands and inter-company actions, while supporting, and in some cases aiding, in the technological prowess of their company. Where criticism can be levelled against management was in their static response to the decline in the armaments business of the 1920s, all sticking to what they knew best and aging along with their companies when they required an influx of new ideas. The end point of 1930 highlighted a change in the structure of the industry, the number of companies involved in Sheffield reduced from five to three through mergers and rationalisation. The story of the industry in the 1930s, through rearmament programs and the Second World War, is worthy of future investigation.

Overall the armaments industry provides an example counter to general notions of British industrial decline. It was the first scientific, high technology industry, one in which the increasingly exacting requirements of their products boosted investment into research and development. In turn, the industry utilised dedicated production facilities, using bespoke machinery so specialised in most cases it was useless for anything other than the batch production runs required for the goods ordered by the governments of the world. It eschewed mass production as it was not needed, even in wartime. Managerially before the Great War each company employed experts to expand their research and development capabilities and build closer links with their home monopsonist buyer. General ideas regarding marketing do not apply given the very limited number of customers available for armaments, instead negotiations and close relationships with home and foreign governments were required. Marketing between companies was also achieved in the licensing of technology, putting Sheffield at the centre of an international network of armaments producers.

By 1914 no other industrial centre could rival the technological expertise of the Sheffield armaments industry. The technocrats involved expertly used systematic research to refine armaments products, their work strongly influenced by metallurgy. Consequently, much of the knowledge derived from their experimental work provided a strong influence on the next generation of developments with metallurgy. Coupled with important productive facilities, the city had customers across the Globe for their output of war material. While the industry declined after the Great War, for several decades Sheffield truly was the ‘Arsenal of the World’.

Word Count: 88,997 (Including all tables and figures)

Appendix A: List Of Patents used in the Study

Section 1: British Patents (95 Total)

Year	Patent Number	Inventor(s) and Company	Title Of Patent
1894	8,971	Robert Abbott Hadfield and Alexander George McKenzie Jack (Hadfields)	Improvements in the Manufacture of Projectiles
1895	24,453	Robert Abbott Hadfield and Alexander George McKenzie Jack (Hadfields)	Improvements in the Manufacture of Cast Steel Hollow Projectiles, and Means for Carrying same into Effect
1896	12,782	Alexander Wilson and Frederic Stubbs (Cammell)	Improvements in Carbonising Iron and Steel
1897	27,753	Robert Abbott Hadfield (Hadfields)	Improved Manufacture of Projectiles
1897	27,754	Robert Abbott Hadfield (Hadfields)	Improved Manufacture of Projectiles
1897	27,755	Robert Abbott Hadfield (Hadfields)	Improved Manufacture of Projectiles
1898	3,543	Robert Abbott Hadfield (Hadfields)	Improvements in the Manufacture of Projectiles
1898	16,901	Robert Abbott Hadfield (Hadfields)	Improvements in Projectiles
1898	20,983	Robert Abbott Hadfield (Hadfields)	Improvements in Projectiles
1898	21,805	Robert Abbott Hadfield (Hadfields)	Improvements in Projectiles
1899	13,670	Robert Abbott Hadfield (Hadfields)	Improvements in the Manufacture of Steel Castings, such as Projectiles
1901	6,089	Robert Abbott Hadfield (Hadfields)	Improvements in the Manufacture or Production of Hardened Steel Projectiles and other Hardened Steel Articles
1901	6,091	Robert Abbott Hadfield (Hadfields)	Improvements in the Manufacture of Projectiles
1902	2,150	Frederick Charles Fairholme and Joseph Ernst Fletcher (Cammell)	Improvements in the Manufacture of Projectiles and in Apparatus therefor
1902	28,376	James Rossiter Hoyle and Alexander Anderson (Firth)	Improvements in Armour Piercing Projectiles

1903	1,850	Frederick Charles Fairholme and Joseph Ernst Fletcher (Cammell)	Improvements in the Manufacture of Armour Plates and Projectiles
1903	8,299	Tolmie John Tresidder (Brown)	Improvements in the Manufacture of Steel Armour Plates, or other Plates of Steel, with a Hardened Face
1903	12,279	Cammell Laird & Company Limited, Frederick Charles Fairholme and Joseph Ernst Fletcher (Cammell)	Improvements in the Manufacture of Hollow Projectiles
1903	12,281	Cammell Laird & Company Limited, Frederick Charles Fairholme and Joseph Ernst Fletcher (Cammell)	Improvements in Projectiles
1903	18,414	James Rossiter Hoyle and Alexander Anderson (Firth)	Improvements in Armour Piercing Projectiles
1903	19,686	Charles Van Cise Wheeler and Alexander George McKenna (Firth-Sterling)	Improvements in Caps for Projectiles
1904	7,882	Robert Abbott Hadfield (Hadfields)	Improvements in or relating to the Manufacture of Projectiles, and of Caps for use therewith
1904	8,037	James Rossiter Hoyle and Alexander Anderson (Firth)	Improvements in Armour Piercing Projectiles
1904	15,219	Robert Abbott Hadfield (Hadfields)	Improvements in or relating to the Manufacture of Projectiles
1906	19,133	Robert Abbott Hadfield (Hadfields)	Improvements in the Manufacture of Gun Houses and other Protective Structures for use in War Ships, Forts and the like
1907	15,976	Cammell Laird & Company Limited, William Archbold Hartley and Bedford Henry Deby (Cammell)	Improvements in the Manufacture of Armour Plates and other Articles
1907	19,104	Robert Abbott Hadfield (Hadfields)	Improvements in or relating to Caps for Armour Piercing Projectiles
1908	2,817	Robert Abbott Hadfield and Alexander George McKenzie Jack (Hadfields)	Improvements in or relating to Capped Armour Piercing Projectiles
1908	6,942	James Rossiter Hoyle and Harry Bland Strange (Firth)	Improvements in Armour Piercing Projectiles

1908	8,105	Robert Abbott Hadfield and Alexander George McKenzie Jack (Hadfields)	Improvements in or relating to Armour Piercing Projectiles and Caps therefor
1908	14,706	Robert Abbott Hadfield (Hadfields)	Improvements in or relating to Armour Clad Vessels and Armour Plates therefor
1908	17,453	Tolmie John Tresidder, James Rossiter Hoyle and Harry Bland Strange (Firth)	Improvements in or relating to Armour Piercing Projectiles
1908	19,062	Tolmie John Tresidder (Brown)	Improvements in Armour Plating
1909	9,215	Edward Kay and Cammell Laird & Company Limited (Cammell)	Improvements in or relating to Projectiles
1909	10,937	James Rossiter Hoyle and Harry Bland Strange (Firth)	Improvements in or relating to Armour Piercing Projectiles
1909	12,055	Vickers, Sons & Maxim Limited, Thomas Edward Vickers and John Lawrence Benthall (Vickers)	Improvements relating to the Manufacture of Armour Plates and other Steel Articles
1909	23,288	James Rossiter Hoyle and Harry Bland Strange (Firth)	Improvements in or relating to Percussion Fuzes for Projectiles
1910	14,899	James Rossiter Hoyle and Harry Bland Strange (Firth)	Improvements in or relating to Percussion Fuzes for Projectiles
1911	6,923	James Rossiter Hoyle and Harry Bland Strange (Firth)	Improvements in or relating to Fuzes for Projectiles
1911	22,899	James Rossiter Hoyle and Harry Bland Strange (Firth)	Improvements in or relating to Fuzes for Projectiles
1911	28,032	James Rossiter Hoyle and Harry Bland Strange (Firth)	Improvements in or relating to Armour Piercing Projectiles
1912	3,901	James Rossiter Hoyle and Harry Bland Strange (Firth)	Improvements in or relating to Fuzes for Projectiles
1912	15,595	Robert Abbott Hadfield (Hadfields)	Improvements in Caps for Armour Piercing Projectiles
1912	21,903	Robert Abbott Hadfield, Alexander George McKenzie Jack and Major Augustus Basil Holt Clerke (Hadfields)	Improvements in or relating to Caps for Armour Piercing Projectiles
1912	29,145	James Rossiter Hoyle and Harry Bland Strange (Firth)	Improvements in or relating to Fuzes for Projectiles
1913	10,607	Robert Abbott Hadfield and Alexander George McKenzie Jack (Hadfields)	Improvements in or relating to Capped Armour Piercing Projectiles and Caps therefor

1913	10,990	James Rossiter Hoyle and Harry Bland Strange (Firth)	Improvements in or relating to Armour Piercing Projectiles
1913	10,991	James Rossiter Hoyle, William Arthur Burton and Harry Bland Strange (Firth)	Improvements in or relating to Armour Piercing Projectiles
1913	17,600	James Rossiter Hoyle and Harry Bland Strange (Firth)	Improvements in or relating to Armour-piercing Projectiles
1914	1,619	Cammell Laird & Company Limited and James McNeal Allan (Cammell)	Improvements in or relating to Caps for Armour Piercing Projectiles
1914	8,875	Thos. Firth & Sons Limited and Harry Bland Strange (Firth)	Improvements in or relating to Armour-piercing Projectiles
1914	8,876	Thos. Firth & Sons Limited and Harry Bland Strange (Firth)	Improvements in or relating to Armour-piercing Projectiles
1915	3,423	John Brown & Company Limited and Tolmie John Tresidder (Brown)	Improvements in the Manufacture of Armour Plates
1915	4,228	Robert Abbott Hadfield and Alexander George McKenzie Jack (Hadfields)	Improvements in or relating to the Manufacture of Metal Ingots
1915	6,993	Robert Abbott Hadfield, Alexander George McKenzie Jack and Issac Bernard Milne (Hadfields)	Improvements in or relating to Projectiles
1916	105,348	Robert Abbott Hadfield and Major Augustus Basil Holt Clerke (Hadfields)	Improvements in or relating to Helmets
1916	124,826	James Rossiter Hoyle and Harry Bland Strang (Firth)	Improvements in or relating to Fuzes for Projectiles
1916	126,048	James Rossiter Hoyle and Harry Bland Strang (Firth)	Improvements in or relating to Time Fuzes and those having Delay Action
1916	126,049	Robert Abbott Hadfield (Hadfields)	Improvements in the Manufacture of Steel
1916	127,601	Robert Abbott Hadfield (Hadfields)	Improvements in or relating to Caps for Armour Piercing Projectiles
1916	127,602	Robert Abbott Hadfield (Hadfields)	Improvements in or relating to the Manufacture or Treatment of Armour Piercing Projectiles
1916	128,961	Robert Abbott Hadfield (Hadfields)	Improvements in or relating to the Manufacture of Shell
1917	120,774	Robert Abbott Hadfield (Hadfields)	Improvements in or relating to Bullets for use in Revolvers and like Firearms

1917	125,671	James Rossiter Hoyle and Harry Bland Strang (Firth)	Improvements in or relating to Armour Piercing Projectiles
1917	127,660	Tolmie John Tresidder (Brown)	Improvements in Devices for Decapping Armour-piercing Shells
1917	127,851	Robert Abbott Hadfield and Sidney Arthur Main (Hadfields)	Improvements in or relating to Bullets
1917	129,367	Tolmie John Tresidder (Brown)	Improvements in Devices for Protecting Turret Roofs, and analogous Structures, against Shells and Projectiles
1917	133,131	Robert Abbott Hadfield (Hadfields)	Improvements in or relating to the Manufacture of Manganese Steel Sheets and Helmets made therefrom
1918	125,737	James Rossiter Hoyle and Harry Bland Strang (Firth)	Improvements in or relating to Projectiles
1918	125,738	James Rossiter Hoyle and Harry Bland Strang (Firth)	Improvements in or relating to Projectiles
1918	130,692	Robert Abbott Hadfield and Alexander George McKenzie Jack (Hadfields)	Improvements in or relating to Caps for Armour Piercing Projectiles
1918	142,143	Robert Abbott Hadfield, Alexander George McKenzie Jack and Issac Bernard Milne (Hadfields)	Improvements in or relating to Armour Piercing Projectiles
1918	142,145	Robert Abbott Hadfield and Alexander George McKenzie Jack (Hadfields)	Improvements in or relating to Armour Piercing Projectiles
1918	142,146	Robert Abbott Hadfield, Alexander George McKenzie Jack and Augustus Basil Holt Clerke (Hadfields)	Improvements in and relating to the Manufacture of Gun Tubes, suitable for use in the Construction of Howitzer and like Guns and for the Linings of Wire-wound and other Guns
1918	142,148	Robert Abbott Hadfield and Alexander George McKenzie Jack (Hadfields)	Improvements in or relating to the Manufacture of Armour Piercing Projectiles, Shells and other Hollow Bodies
1918	142,149	Robert Abbott Hadfield, Alexander George McKenzie Jack, Issac Bernard Milne, James Rossiter Hoyle, Harry Bland Strang and Esmond Morse (Hadfields and Firth)	Improvements in or relating to the Manufacture of Caps for Armour Piercing Projectiles

1919	164,056	Robert Abbott Hadfield, Alexander George McKenzie Jack and Augustus Basil Holt Clerke (Hadfields)	Improvements in or relating to Capped Armour Piercing Projectiles
1921	184,920	Cammell Laird & Company Limited, James McNeal Allan, Alexander Parker Hague and Thomas Middleton (Cammell)	Improvements in or relating to the Cementation of Iron, Steel and Ferrous Alloys
1922	202,681	Robert Abbott Hadfield and Augustus Basil Holt Clerke (Hadfields)	Improvements in or relating to Armour Piercing Projectiles
1922	208,803	William Herbert Hatfield and Harry Green (Firth)	Improvements in or relating to Alloy Steels
1923	220,006	Robert Abbott Hadfield (Hadfields)	Improvements in or relating to Alloys
1923	232,656	Robert Abbott Hadfield (Hadfields)	Improvements in or relating to Alloys
1925	251,837	Tolmie John Tresidder (Brown)	Improvements in Micrometer Screw Gauges of the Beam Type
1926	250,148	Tolmie John Tresidder (Brown)	Improvements in Instruments for Measuring Angles
1926	265,503	Tolmie John Tresidder (Brown)	Improvements in Micrometer Calliper Gauges
1927	276,249	Cammell Laird & Company Limited, James McNeal Allan, and Alexander Parker Hague (Cammell)	Improvements in or relating to Alloy Steels
1927	302,812	William Herbert Hatfield and Harry Green (Firth)	Improvements in the Manufacture of Metal Articles and Alloys therefor
1928	313,471	Robert Abbott Hadfield (Hadfields)	Improvements in or relating to Alloys
1928	316,394	William Herbert Hatfield and Harry Green (Firth)	Improvements in or relating to Metal Articles for use in Chemical and like Processes and Alloys therefor
1929	325,963	Tolmie John Tresidder (Brown)	Improvements in Setting Rods for use with Micrometer Gauges
1929	329,966	Harry Bland Strang and Harry Green (Firth)	Improvements in or relating to Armour Piercing Projectiles
1929	329,967	Harry Bland Strang and Harry Green (Firth)	Improvements in or relating to Projectiles

1929	333,237	William Herbert Hatfield and Harry Green (Firth)	A Method of, or Process for, Rendering Austenitic Nickel-chromium Steels Non-corrodible
1930	352,548	Robert Abbott Hadfield (Hadfields)	New or Improved Manufacture of Material suitable for Resisting Rifle Bullets and other Projectiles and for other purposes
1930	353,425	Robert Abbott Hadfield and Augustus Basil Holt Clerke (Hadfields)	Improvements in or relating to Armour Piercing Projectiles

Section 2: US Patents (10 Total)

Year	Patent Number	Inventor(s) and Company	Title Of Patent
1903	721,487	Charles Van Cise Wheeler and Alexander George McKenna (Firth-Sterling)	Projectile
1903	725,385	Charles Van Cise Wheeler and Alexander George McKenna (Firth-Sterling)	Projectile
1904	748,827	Charles Van Cise Wheeler and Alexander George McKenna (Firth-Sterling)	Cap for Projectile
1906	815,992	Charles Van Cise Wheeler and Alexander George McKenna (Firth-Sterling)	Projectile and its Band
1907	841,753	Charles Van Cise Wheeler and Alexander George McKenna (Firth-Sterling)	Projectile
1907	875,023	Charles Van Cise Wheeler and Alexander George McKenna (Firth-Sterling)	Projectile
1908	893,963	Charles Van Cise Wheeler and Alexander George McKenna (Firth-Sterling)	Projectile
1910	950,586	Charles Van Cise Wheeler and Alexander George McKenna (Firth-Sterling)	Capped Armor-Piercing Projectile
1910	963,489	Charles Van Cise Wheeler and Alexander George McKenna (Firth-Sterling)	Projectile
1910	968,012	Charles Van Cise Wheeler and Alexander George McKenna (Firth-Sterling)	Cap for Armor-Piercing Projectile

Appendix B: Hadfields' and Firth's British Government Projectile Orders 1900-1914

Section 1: Hadfields' Orders

Order Date	Customer	Quantity	Description	Value
10 February 1900	British Army	10,000	15 pound shrapnel shell, Hadfields cast steel	£10,387
24 February 1900	British Navy	30,000	4.7 inch common, pointed, cast steel shell	£26,400
24 February 1900	British Navy	40,000	12 pound common, pointed, cast steel shell	£19,050
01 March 1900	British Army	10,000	12 pound shrapnel cast steel shell	£8,985
21 March 1900	British Navy	200	12 inch heavy armour piercing shot	£10,508
14 May 1900	British Navy	800	12 inch heavy armour piercing shell	£32,984
14 May 1900	British Navy	800	9.2 inch armour piercing shell	£15,664
14 May 1900	British Navy	600	8 inch armour piercing shell	£6,652
14 May 1900	British Navy	10,400	6 inch armour piercing shell	£46,540
07 June 1900	British Army	7,360	12 pound common, pointed, cast steel shell	£3,569
07 June 1900	British Navy	4,000	12 inch heavy common, pointed, cast steel shell	£49,200
07 June 1900	British Navy	300	9.2 inch common, pointed, cast steel shell	£2,231
07 June 1900	British Navy	900	8 inch common, pointed, cast steel shell	£4,050
07 June 1900	British Navy	40,000	6 inch common, pointed, cast steel shell	£62,299
07 June 1900	British Navy	10,000	4 inch common, pointed, cast steel shell	£6,800
07 June 1900	British Navy	36,000	4.7 inch common, pointed, cast steel shell	£22,620
07 June 1900	British Navy	30,000	12 pound common, pointed, cast steel shell	£14,250
26 June 1900	British Army	5,000	9.2 inch armour piercing shell	£86,853
03 July 1900	British Army	2,000	4.7 inch shrapnel shell	£3,870
13 July 1900	British Navy	400	13.5 inch armour piercing shell	£20,645
25 July 1900	British Army	10,000	6 inch armour piercing shell	£38,975
16 August 1900	British Army	200	6 inch high explosive shell, Hadfields cast steel	£630
16 November 1900	British Navy	500	13.5 inch armour piercing shell	£26,875
16 November 1900	British Navy	400	12 inch light armour piercing shell	£15,084
16 November 1900	British Navy	1,000	12 inch heavy armour piercing shell	£35,500
16 November 1900	British Navy	500	10 inch armour piercing shell	£11,414
16 November 1900	British Navy	400	9.2 inch armour piercing shell	£6,900
16 November 1900	British Navy	15,000	6 inch armour piercing shell	£58,349
03 December 1900	British Navy	1,200	4 inch common, pointed shell	£813
03 December 1900	British Navy	10,000	12 pound, common, pointed shell	£4,675
15 February 1901	British Army	6	Fit six 6 inch AP shells with caps	£12
06 May 1901	British Navy	1,600	12 inch heavy common, pointed, cast steel shell	£19,514
06 May 1901	British Navy	1,200	9.2 inch common, pointed, cast steel shell	£8,040
06 May 1901	British Navy	8,000	4 inch common, pointed, cast steel shell	£5,279
06 May 1901	British Navy	10,000	12 pound common, pointed, cast steel shell	£4,575
13 May 1901	British Navy	200	12 inch heavy armour piercing shot	£9,950
13 May 1901	British Navy	600	6 inch armour piercing shot	£3,574
15 May 1901	British Navy	5,000	6 inch armour piercing shell	£18,500
22 May 1901	British Army	10	6 pound unharded shell for trial	£17
31 May 1901	British Army	7,000	4.7 inch shrapnel shell	£11,201

15 June 1901	British Army	1	6 inch uncapped armour piercing shell	£3
04 July 1901	British Navy	1,000	6 inch common, pointed practice shell	£806
30 May 1901	British Army	12	7.5 inch armour piercing shell	£93
08 August 1901	British Army	1	6 inch AP shot to be fired at KNC plate at 20 deg.	£0
10 September 1901	British Army	10,000	12 pound common, pointed, cast steel shell	£4,533
11 September 1901	British Navy	800	12 inch heavy armour piercing shell	£26,368
03 October 1901	British Army	450	6 inch cast steel practice shell	£480
18 December 1901	British Army	10,000	6 inch armour piercing shell	£32,500
20 January 1902	British Army	250	12 pound common shell	£50
20 January 1902	British Army	260	6 inch armour piercing shell	£205
20 January 1902	British Army	8	9.2 inch common steel shell	£20
20 January 1902	British Army	12	9.2 inch armour piercing shell	£35
20 January 1902	British Army	4	10 inch common shell	£19
07 April 1902	British Navy	9	12 inch light armour piercing shell	£42
07 April 1902	British Navy	5	12 inch heavy common shell	£27
07 April 1902	British Navy	70	12 inch heavy armour piercing shell	£390
07 April 1902	British Navy	18	13.5 inch armour piercing shell	£127
01 May 1902	British Navy	2,000	6 inch cast steel shrapnel shell	£5,002
01 May 1902	British Navy	1,600	6 inch armour piercing shell in Hadfields cast steel	£7,702
23 May 1902	British Navy	50,000	12 pound common, pointed, cast steel shell	£20,674
26 May 1902	British Army	13,500	12 pound common, pointed, cast steel shell	£5,568
17 March 1902	British Army	3	6 inch improved cast steel AP shot capped	£16
09 June 1902	British Navy	300	13.5 inch armour piercing shell, cast steel	£13,635
09 June 1902	British Navy	43,000	6 inch solid shot, cast iron	£33,150
09 June 1902	British Navy	400	13.5 inch solid shot, cast iron, for practice	£2,887
09 June 1902	British Navy	600	12 inch heavy solid shot, cast iron, for practice	£3,404
09 June 1902	British Navy	300	12 inch light solid shot, cast iron, for practice	£1,516
14 June 1902	British Army	833	12 inch light armour piercing shell	£24,996
14 June 1902	British Army	365	10 inch armour piercing shell, Hadfields cast steel	£7,490
14 June 1902	British Army	1,632	9.2 inch armour piercing shell, Hadfields cast steel	£27,578
14 June 1902	British Army	7,600	6 inch armour piercing shell in Hadfields cast steel	£25,843
07 July 1902	British Navy	10,000	6 inch armour piercing shell in Hadfields cast steel	£32,526
17 July 1902	British Army	62	4.7 inch common shell	£25
17 July 1902	British Army	287	6 inch common shell	£210
17 July 1902	British Army	269	6 inch armour piercing shell	£196
17 July 1902	British Army	46	6 inch armour piercing shot	£33
17 July 1902	British Army	4	9.2 inch common shell	£14
17 July 1902	British Army	22	9.2 inch armour piercing shell	£65
18 October 1902	British Army	5,000	12 pound common, pointed, cast steel shell	£2,049
25 March 1903	British Navy	17,000	4.7 inch solid shot, cast iron	£5,847
15 May 1903	British Navy	500	12 inch heavy, common, pointed, cast steel shell	£5,004

15 May 1903	British Navy	8,000	12 pound, common, pointed, cast steel shell	£3,111
26 May 1903	British Army	200	9.2 inch common lyddite shell	£2,104
24 June 1903	British Navy	5,000	6 inch common, pointed, cast steel shell	£7,132
24 June 1903	British Navy	9,000	4 inch common, pointed, cast steel shell	£4,930
30 June 1903	British Navy	1,200	9.2 inch armour piercing shell, cast steel	£13,305
30 June 1903	British Navy	20,000	6 inch armour piercing shell, cast steel	£53,238
08 July 1903	British Navy	1,600	12 inch heavy armour piercing shell	£37,741
21 July 1903	British Army	200	6 inch shot, forged	£209
21 July 1903	British Army	200	4.7 inch shot, forged	£104
08 October 1903	British Army	400	6 inch armour piercing shell	£1,050
10 October 1903	British Army	3	6 inch Heclon projectiles	£15
06 January 1904	British Navy	40	6 inch common shell	£24
06 January 1904	British Navy	190	6 inch armour piercing shell	£116
06 January 1904	British Navy	126	6 inch armour piercing shot	£77
06 January 1904	British Navy	27	9.2 inch armour piercing shell	£58
06 January 1904	British Navy	19	12 inch light armour piercing shell	£87
06 January 1904	British Navy	34	12 inch heavy armour piercing shell	£170
29 January 1904	British Army	200	6 inch common, pointed, cast steel shell	£255
30 January 1904	British Army	4	6 inch Heclon projectiles	£20
25 February 1904	British Navy	1,200	7.5 inch common, pointed shell	£4,275
10 March 1904	British Navy	800	7.5 inch armour piercing shell with cap	£11,235
28 March 1904	British Navy	7,000	4 inch solid shot, cast iron	£1,431
26 April 1904	British Navy	400	12 inch heavy armour piercing shell	£8,986
26 April 1904	British Navy	800	9.2 inch armour piercing shell	£8,503
26 April 1904	British Navy	1,600	7.5 inch armour piercing shell	£22,325
02 May 1904	British Navy	600	12 inch heavy cast iron shot	£2,934
11 May 1904	British Army	84	6 inch pointed common shell	£152
20 May 1904	British Army	9,000	5 inch solid shot	£2,475
31 May 1904	British Navy	2,200	7.5 inch common, pointed, cast steel shell	£8,226
21 June 1904	British Navy	2,000	6 inch armour piercing shell	£5,079
21 June 1904	British Navy	4,000	6 inch armour piercing shell with cap (Heclon)	£25,980
02 August 1904	British Navy	300	10 inch solid shot	£837
12 August 1904	British Navy	8,000	4.7 inch solid shot	£2,229
01 September 1904	British Army	889	6 inch armour piercing shell with cap (Heclon)	£5,772
19 September 1904	British Navy	3,000	6 inch solid shot	£1,913
30 September 1904	British Navy	800	9.2 inch armour piercing shell	£8,617
11 October 1904	British Army	10	6 inch cast steel common shell	£23
01 December 1904	British Navy	600	10 inch common, pointed shell	£4,800
01 December 1904	British Navy	1,000	7.5 inch common, pointed shell	£3,800
22 December 1904	British Navy	10,000	12 pound common, pointed shell	£3,710
02 January 1905	British Navy	1,600	6 inch armour piercing shell with cap (Heclon)	£8,270
02 January 1905	British Navy	800	7.5 inch armour piercing shell with cap (Heclon)	£7,908
02 January 1905	British Navy	800	7.5 inch armour piercing shell with cap (Heclon)	£7,840
02 January 1905	British Army	15	6 inch shell	£35

09 January 1905	British Navy	300	10 inch armour piercing shell with cap (Heclon)	£7,057
09 January 1905	British Navy	800	9.2 inch armour piercing shell with cap (Heclon)	£14,728
11 January 1905	British Navy	400	12 inch heavy solid shot	£1,876
11 January 1905	British Army	52,000	18 pound shrapnel shell	£46,468
25 January 1905	British Army	700	7.5 inch armour piercing shell with cap (Heclon)	£6,825
25 January 1905	British Army	400	6 inch armour piercing shell with cap (Heclon)	£2,048
10 February 1905	British Navy	800	12 inch heavy armour piercing shell with cap (Heclon)	£26,766
24 March 1905	British Army	45,000	18 pound shrapnel shell	£32,981
25 May 1905	British Navy	200	10 inch solid shot	£542
25 May 1905	British Navy	6,000	6 inch solid shot	£3,642
10 June 1905	British Navy	5,000	12 pound common pointed shell	£1,862
31 July 1905	British Army	810	6 inch armour piercing shell with cap (Heclon)	£4,235
05 September 1905	British Navy	2,800	12 inch heavy armour piercing shell with cap (Heclon)	£81,914
05 September 1905	British Navy	2,400	9.2 inch armour piercing shell with cap (Heclon)	£39,920
05 September 1905	British Navy	1,200	7.5 inch armour piercing shell with cap (Heclon)	£11,285
03 November 1905	British Army	400	9.2 inch armour piercing shell with cap (Heclon)	£6,400
06 December 1905	British Navy	10,000	12 pound common pointed shell	£3,981
07 December 1905	British Army	3,000	5 inch solid shot	£940
08 September 1905	British Army	4	7.5 inch armour piercing shell with cap (Heclon)	£43
20 January 1906	British Army	25	Cast steel bodies for 60 pound shrapnel shell	£18
17 February 1906	British Army	5	6 inch armour piercing shell with cap (Heclon)	£30
18 May 1906	British Army	4	7.5 inch armour piercing shell with cap (Eron)	£40
28 May 1906	British Navy	1,200	12 inch heavy solid shot	£5,398
28 May 1906	British Navy	1,000	7.5 inch solid shot	£1,258
28 May 1906	British Navy	1,000	7.5 inch solid shot	£1,240
28 May 1906	British Navy	2,500	6 inch solid shot	£1,650
16 June 1906	British Navy	20,000	12 pound common, pointed shell	£6,968
19 December 1906	British Navy	10,000	12 pound common lyddite shell	£4,661
06 July 1906	British Navy	3,000	7.5 inch common, pointed shell	£10,174
11 July 1906	British Army	2	7.5 inch armour piercing shell with caps	£22
08 August 1906	British Navy	1,100	12 inch heavy, common, pointed, cast steel shell	£11,833
15 August 1906	British Army	2	12 inch AP shell	£65
15 August 1906	British Army	2	7.5 inch AP shell	£20
29 October 1906	British Navy	6	12 inch armour piercing capped shell (Eron)	£195

15 January 1907	British Army	2	12 inch Eron AP Shell with caps	£37
15 January 1907	British Army	2	12 inch AP shell without caps	£33
11 January 1907	British Army	2	7.5 inch common, pointed shell with cap (Eron)	£25
17 January 1907	British Navy	3,000	12 pound common lyddite shell	£1,170
27 February 1907	British Army	6	12 inch Eron capped shell	£111
08 February 1907	British Army	20,000	18 pound shrapnel shell	£15,340
13 April 1907	British Navy	800	12 armour piercing shell with cap	£24,812
19 April 1907	British Army	6	7.5 inch capped common pointed shell	£60
15 May 1907	British Army	1	7.5 inch capped common pointed shell	£10
22 June 1907	British Navy	7	7.5 inch AP shell	£8
22 June 1907	British Navy	1	12 inch AP shell	£4
29 June 1907	British Army	17,500	18 pound shrapnel shell	£13,575
04 October 1907	British Army	1	7.5 inch Eron shell fitted with our patent cap	£10
10 October 1907	British Navy	4,800	12 inch heavy, common, pointed shell with cap (Eron)	£119,925
18 November 1907	British Army	2	12 inch common, pointed shell with cap	£9
18 November 1907	British Army	5	7.5 inch Heclon AP Shell	£6
27 November 1907	British Army	4	9.2 inch Eron capped common pointed shell	£69
04 February 1908	British Navy	5,000	4 inch heavy common, pointed shell	£3,450
27 May 1908	British Army	4	12 inch AP shell with cap to our design	£140
05 June 1908	British Navy	100	12 inch common shell with cap (Eron)	£1,750
05 June 1908	British Navy	100	12 inch common shell with cap (Eron)	£1,750
17 May 1908	British Navy	800	12 inch heavy common, pointed shell with cap (Eron)	£20,774
25 August 1908	British Navy	20	12 inch lyddite shell	£530
02 September 1908	British Navy	2,000	4 inch heavy common, pointed shell	£1,425
05 September 1908	British Navy	800	7.5 inch common, pointed with cap (Eron)	£7,144
17 September 1908	British Navy	20	6 inch common pointed shell with cap	£80
17 September 1908	British Navy	20	6 inch common pointed shell with cap (Different)	£80
17 September 1908	British Navy	35	6 inch lyddite shell	£147
17 September 1908	British Navy	35	6 inch lyddite shell (Different)	£147
28 October 1908	British Army	2	12 inch Heclon AP shell with cap	£132
28 October 1908	British Army	2	12 inch Eron common shell with cap	£132
16 December 1908	British Navy	400	12 inch heavy armour piercing shell with cap	£9,938
29 December 1908	British Navy	400	12 inch heavy armour piercing shell with cap	£10,113
26 January 1909	British Army	2	7.5 inch Eron common pointed shell with cap	£17
29 January 1909	British Army	2	12 inch Heclon capped shell with 8 calibre head	£66
04 February 1909	British Army	5	9.2 inch high explosive armour piercing shell	£87
12 February 1909	British Navy	20	9.2 inch common cast iron shell	£100
12 February 1909	British Navy	10	7.5 inch common cast iron shell	£27
12 February 1909	British Navy	10	6 inch common cast iron shell	£13
16 March 1909	British Army	20	9.2 inch lyddite shell	£265

06 April 1909	British Navy	300	12 inch heavy common lyddite shell	£5,070
07 April 1909	British Army	20	12 inch heavy common shell with cap	£361
05 May 1909	British Navy	3	9.2 inch common shell with cap	£53
15 June 1909	British Army	20	12 inch heavy cast steel practice shell with cap	£275
10 June 1909	British Navy	6,000	4 inch heavy common, pointed shell	£1,556
05 July 1909	British Army	50	6 inch common lyddite shell	£195
23 October 1909	British Navy	10,000	4 inch heavy common lyddite shell	£8,135
01 October 1909	British Navy	400	12 inch heavy common, pointed shell with cap (Eron)	£10,050
01 October 1909	British Navy	400	12 inch heavy common lyddite shell	£6,300
05 October 1909	British Navy	3	6 inch common capped shell (Eron)	£15
21 August 1909	British Navy	40	12 inch Eron common capped shell	£903
21 August 1909	British Navy	10	12 inch Heclon AP shell	£221
21 August 1909	British Navy	10	12 inch lyddite shell	£221
21 August 1909	British Navy	40	12 inch Eron common capped shell	£903
21 August 1909	British Navy	10	12 inch Heclon AP shell	£221
21 August 1909	British Navy	10	12 inch lyddite shell	£221
06 October 1909	British Navy	40	12 inch Eron common capped shell	£898
06 October 1909	British Navy	10	12 inch Heclon AP shell	£220
06 October 1909	British Navy	10	12 inch lyddite shell	£220
21 August 1909	British Navy	6	12 inch lyddite shell	£120
06 October 1909	British Navy	5	12 inch lyddite shell	£119
06 October 1909	British Navy	4	12 inch Eron common capped shell	£168
06 October 1909	British Navy	4	12 inch Heclon AP shell	£168
06 October 1909	British Navy	4	12 inch Eron common capped shell	£168
06 October 1909	British Navy	4	12 inch Heclon AP shell	£168
15 October 1909	British Navy	4	12 inch Eron common capped shell	£168
15 October 1909	British Navy	4	12 inch Heclon AP shell	£168
22 November 1909	British Army	3	7.5 inch common pointed shell with cap	£26
22 November 1909	British Army	3	7.5 inch common pointed shell	£25
22 February 1910	British Army	8	12 inch lyddite shell	£238
22 February 1910	British Army	10	12 inch lyddite shell	£240
24 February 1910	British Navy	400	6 inch Eron common, pointed, cast steel shell with cap	£2,160
21 March 1910	British Navy	800	12 inch heavy armour piercing shell with cap	£20,158
02 June 1910	British Navy	50	13.5 inch common, pointed projectile with cap	£1,200
03 June 1910	British Navy	500	7.5 inch practice shot	£638
27 June 1910	British Navy	50	13.5 inch common, pointed projectile with cap	£1,175
31 October 1910	British Navy	800	6 inch common, pointed with cap	£3,873
02 September 1910	British Navy	8,000	12 and 14 pound practice shot	£732
02 September 1910	British Navy	1,000	7.5 inch practice shot	£1,277
05 September 1910	British Navy	400	12 inch heavy armour piercing shell with cap	£10,053
12 September 1910	British Navy	1,200	13.5 inch armour piercing shell with cap (Heclon)	£55,154
12 September 1910	British Navy	800	13.5 inch common, pointed projectile with cap (Eron)	£37,520

06 October 1910	British Army	117	9.2 inch heavy common lyddite shell	£758
19 January 1911	British Navy	2	13.5 inch armour piercing shell with cap	£92
02 February 1911	British Navy	26	13.5 inch armour piercing shell with cap (Heclon)	£851
02 February 1911	British Navy	3	13.5 inch armour piercing shell with cap (Heclon)	£145
02 February 1911	British Navy	26	13.5 inch common pointed shell with cap (Eron)	£858
02 February 1911	British Navy	3	13.5 inch common pointed shell with cap (Eron)	£148
02 February 1911	British Navy	16	13.5 inch common lyddite shell	£456
02 February 1911	British Navy	26	13.5 inch armour piercing shell with cap (Heclon)	£851
02 February 1911	British Navy	3	13.5 inch armour piercing shell with cap (Heclon)	£145
02 February 1911	British Navy	26	13.5 inch common pointed shell with cap (Eron)	£858
02 February 1911	British Navy	3	13.5 inch common pointed shell with cap (Eron)	£148
02 February 1911	British Navy	16	13.5 inch common lyddite shell	£456
27 April 1911	British Navy	21	13.5 inch representative common capped shell	£672
13 June 1911	British Navy	2,800	6 inch common pointed shell with cap (Eron)	£13,533
13 July 1911	British Navy	800	12 inch heavy common pointed shell with cap (Eron)	£19,776
13 July 1911	British Navy	2,000	6 inch common lyddite shell	£4,533
13 July 1911	British Navy	31,600	4 inch heavy common lyddite shell	£28,875
04 August 1911	British Navy	7,500	4 inch heavy common lyddite shell	£6,765
17 August 1911	British Navy	2,000	13.5 inch heavy common pointed shell with cap (Eron)	£90,735
17 August 1911	British Navy	2,000	13.5 inch heavy armour piercing shell with cap (Heclon)	£86,000
22 August 1911	British Army	2,775	4.5 inch common lyddite howitzer shell	£2,771
04 October 1911	British Navy	5	Projectiles representative of 13.5 inch AP with cap	£135
04 October 1911	British Navy	5	Projectiles representative of 13.5 inch common capped	£136
12 October 1911	British Navy	400	13.5 inch heavy common lyddite shell	£11,508
26 October 2011	British Navy	10	Projectiles representative of 12 inch heavy AP with cap	£135
09 January 1912	British Army	7	9.2 inch representative AP shell with cap	£94
15 February 1912	British Navy	1,600	13.5 inch heavy armour piercing shell with cap	£70,087
15 February 1912	British Navy	800	13.5 inch heavy common pointed shell with cap	£36,840
02 April 1912	British Navy	10	6 inch capped common shell (Eron)	£48
26 March 1912	British Army	4	9.2 inch representative AP shell with cap	£53
09 August 1912	British Navy	37,000	4 inch heavy common lyddite shell	£41,836
18 September 1912	British Navy	3,000	6 inch common lyddite shell	£8,119

06 November 1912	British Navy	2,800	6 inch common, pointed shell with cap (Eron)	£16,827
28 November 1912	British Navy	400	13.5 inch heavy common pointed shell with cap (Eron)	£20,016
13 December 1912	British Navy	2	14 inch Heclon armour piercing capped	£136
13 December 1912	British Navy	2	14 inch Eron common pointed with cap	£141
15 January 1913	British Navy	10	6 inch armour piercing with cap, filled with salt	£62
03 February 1913	British Navy	800	13.5 inch light common pointed shell with cap (Eron)	£35,931
17 April 1913	British Navy	400	12 inch heavy common pointed shell with cap (Eron)	£10,213
28 May 1913	British Navy	1,600	15 inch armour piercing shell with cap (Heclon)	£102,215
31 May 1913	British Navy	4,000	6 inch common pointed shell with cap (Eron)	£25,324
11 June 1913	British Navy	2	Representative 15 inch Eron common pointed capped	£124
07 August 1913	British Navy	6,000	4 inch heavy practice shot	£1,696
09 August 1913	British Army	625	9.2 inch armour piercing shell with cap	£10,426
26 July 1913	British Navy	1,200	15 inch common pointed shell with cap (Eron)	£79,158
24 November 1913	British Navy	205	12 inch heavy armour piercing shell with cap	£469
08 December 1913	British Navy	12,000	4 inch heavy common lyddite shell	£16,936
10 December 1913	British Army	9	6 inch armour piercing Heclon shell	£54
21 January 1914	British Navy	400	13.5 inch common pointed shell with cap (Eron)	£18,482
21 January 1914	British Navy	1,200	13.5 inch heavy armour piercing shell with cap	£53,122
21 January 1914	British Navy	800	15 inch common pointed shell with cap (Eron)	£49,326
21 January 1914	British Navy	400	15 inch armour piercing shell with cap	£23,760
22 January 1914	British Navy	10	6 inch armour piercing Heclon shell	£62
17 March 1914	British Navy	1,600	6 inch common pointed shell with cap	£9,523
20 April 1914	British Army	500	9.2 inch heavy practice shot	£1,074
03 July 1914	British Navy	1,600	15 inch armour piercing shell with cap	£96,201
03 July 1914	British Navy	2,800	15 inch common pointed shell with cap (Eron)	£172,889
03 July 1914	British Navy	400	12 inch heavy common pointed shell with cap (Eron)	£9,868
03 July 1914	British Navy	4,000	6 inch common pointed shell with cap (Eron)	£23,969
15 July 1914	British Navy	7,500	4 inch heavy common lyddite shell	£10,593
08 August 1914	British Army	800	9.2 inch armour piercing shell with cap	£14,266

Source: Sheffield Archives, Hadfields Projectile Order Books Volume 1 to 3.

Section 2: Firth's Orders

Order Date	Customer	Quantity	Description	Value
27 January 1900	British Army	1,000	5 inch common lyddite shell	£2,100
02 March 1900	British Army	6,000	6 inch armour piercing shell	£34,500
14 May 1900	British Navy	2,000	6 inch armour piercing shell	£11,840
14 May 1900	British Navy	400	12 inch armour piercing heavy shell	£19,800
14 May 1900	British Navy	800	9.2 inch armour piercing shell	£19,600
13 July 1900	British Navy	400	13.5 inch Armour Piercing Shell	£25,600
16 November 1900	British Navy	8,000	6 inch armour piercing shell	£39,600
16 December 1900	British Navy	500	13.5 inch Armour Piercing Shell	£31,000
14 June 1902	British Army	833	12 inch armour piercing light projectile	£24,115
14 June 1902	British Army	365	10 inch armour piercing shell	£7,099
14 June 1902	British Army	3,680	9.2 inch armour piercing shell	£55,016
14 June 1902	British Army	100	8 inch armour piercing shell	£945
14 June 1902	British Army	12,000	6 inch armour piercing shell	£37,500
16 April 1903	British Navy	200	6 inch armour piercing shot	£1,300
30 June 1903	British Navy	6,000	6 inch armour piercing shell	£14,250
06 August 1903	British Army	400	9.2 inch armour piercing shell	£3,750
12 January 1904	British Army	400	9.2 inch cast steel shrapnel shell	£2,700
10 March 1904	British Navy	1,600	7.5 inch armour piercing shell	£22,400
28 March 1904	British Navy	1,000	12 inch light solid shot	£3,320
26 April 1904	British Navy	800	7.5 inch armour piercing shell	£11,200
26 April 1904	British Navy	800	7.5 inch armour piercing shell	£11,200
21 June 1904	British Navy	2,000	6 inch armour piercing shell with cap	£13,250
01 September 1904	India Office	888	6 inch armour piercing shell with cap	£5,772
09 January 1905	British Navy	300	10 inch armour piercing shell with cap	£7,800
11 January 1905	British Navy	300	12 inch heavy solid shot	£1,275
01 April 1905	British Navy	400	9.2 inch armour piercing shell with cap	£7,400
31 July 1905	British Army	810	6 inch armour piercing shell with cap	£3,827
05 September 1905	British Navy	800	12 inch heavy armour piercing shell with cap	£25,600
05 September 1905	British Navy	3,200	9.2 inch armour piercing shell with cap	£51,200
05 September 1905	British Navy	400	7.5 inch armour piercing shell with cap	£3,750
03 November 1905	British Army	400	9.2 inch armour piercing shell with cap	£6,400
September1908	British Navy	715	Common Shell	£10,000
January 1909	British Navy	800	12 inch Projectiles	£17,000
October 1909	British Navy	400	12 inch AP projectiles	
October 1909	British Navy	500	12 inch Lyddite shell	£17,000
June 1910	British Navy		4 inch lyddite shell	£10,000
September 1910	British Navy	800	13.5 inch armour piercing shell	As below
September 1910	British Navy	800	13.5 inch common pointed shell	£87,000
13 June 1911	British Navy	400	6 inch common shell	£2,000

August 1911	British Navy	2,400	13.5 inch projectiles	£100,000
27 February 1912	British Navy	400	13.5 inch AP	As Below
27 February 1912	British Navy	400	13.5 inch Common	£39,400
15 October 2012	British Navy	400	6 inch common pointed with cap	£2,450
21 October 1912	British Army	200	9.2 inch armour piercing shell with cap	£3,300
28 September 1912	British Navy	3,200	6 inch common pointed with cap	£19,600
03 February 1913	British Navy	400	13.5 inch light armour piercing shell with cap	£16,800
28 May 1913	British Navy	800	15 inch armour piercing shell with cap	£53,200
31 May 1913	British Navy	1,600	6 inch common pointed shell with cap	£9,920
14 July 1913	British Navy	400	15 inch common pointed shell with cap	£27,548
18 July 1913	British Army	200	9.2 inch armour piercing shell with cap	£3,325
21 January 1914	British Navy	20	15 inch armour piercing shell with cap	£1,260
21 January 1914	British Navy	380	15 inch armour piercing shell with cap	£23,940
21 January 1914	British Navy	420	15 inch common pointed shell with cap	£27,668
21 January 1914	British Navy	380	15 inch common pointed shell with cap	£25,032
21 January 1914	British Navy	1,200	13.5 inch common pointed shell with cap	£52,200
June 1914	British Navy	*Unknown*	*Details unknown*	£100,000

Source: Sheffield Archives, Firth Records; The National Archives, Director of Naval Contracts Annual Reports 1900-1914.

Appendix C: Hadfields' and Firth's British Government Projectile Orders 1920-1930

Section 1: Hadfields' Orders

Order Date	Customer	Quantity	Description	Value
12 March 1920	British Navy	800	15 inch Armour Piercing with Cap	£118,773
19 June 1920	British Navy	21	15 inch Armour Piercing with Cap	£2,835
17 July 1920	British Navy	200	15 inch Shell APC (Improved type for trials)	£30,775
27 September 1920	British Army	800	13.5 inch Shell APC Heavy	£92,960
01 December 1920	British Army	2	15 inch APC Shell Light	£270
09 December 1920	British Navy	1	15 inch APC Shell Light	£135
25 January 1921	British Navy	3	16 inch Shell APC 50 calibre	£1,200
26 February 1921	British Navy	600	15 inch Shell APC, New Type	£82,347
11 June 1921	British Navy	18	15 inch Shell APC Special Experimental	£2,555
23 July 1921	British Navy	15	6 inch APC and AP Shells 4% capacity	£373
23 September 1921	British Navy	4	15 inch APC double capped	£800
08 December 1921	British Navy	12	6 inch APC and AP Shells 4% capacity	£268
10 December 1921	British Navy	1,800	15 inch Armour Piercing Capped	£260,678
12 January 1922	British Navy	8	6 inch AP uncapped	£179
30 January 1922	British Navy	12	15 inch SAP Shell	£1,668
02 March 1922	British Navy	10	6 inch AP with Ballistic Caps	£223
08 May 1922	British Navy	20	6 inch AP representative	£206
29 June 1922	British Navy	100	0.308 inch Armour Piercing Bullets Capped Type	£17
30 June 1922	British Navy	2	16 inch APC shell	£320
18 July 1922	British Navy	4	15 inch SAP Shell	£530
03 August 1922	British Navy	800	15 inch APC	£101,296
21 August 1922	British Navy	250	16 inch APC representative	£14,812
25 August 1922	British Navy	12	4.7 inch Semi AP Shell	£142
01 September 1922	British Navy	9	6 inch AP Shell	£165
20 September 1922	British Navy	12	6 inch APC Shell	£257
20 September 1922	British Navy	2	6 inch empty APC	£82
25 September 1922	British Navy	12	16 inch APC shell	£1,589
09 October 1922	British Navy	4	16 inch APC shell	£550
16 October 1922	British Navy	12	7.5 inch APC Shell	£426
28 September 1922	British Navy	40	0.303 Special Armour Piercing Bullets	£10
20 November 1922	British Navy	6	6 inch AP with Ballistic Caps	£125
19 December 1922	British Navy	30	6 inch AP representative	£358
19 December 1922	British Navy	6	6 inch AP Shell	£112
28 December 1922	British Navy	10	15 inch APC Shell New Type	£307
05 February 1923	British Navy	4	15 inch (Speical) APC Shell	£472
06 April 1923	British Navy	4	6 inch APC Shell	£90
18 April 1923	British Navy	6	6 inch APC Shell	£135
24 April 1923	British Navy	1,600	6 inch common pointed shell with Ballistic Cap	£19,164
30 April 1923	British Navy	720	5.2 inch Semi AP Shell	£4,618
11 May 1923	British Navy	60	5.2 inch SAP Representative shell	£257
01 June 1923	British Navy	4,800	6 inch common pointed shell with Ballistic	£53,820

			Cap	
16 June 1923	British Navy	380	6 inch AP representative shell	£4,506
14 July 1923	British Navy	600	15 inch APC Shell	£76,012
07 August 1923	British Navy	10	4.7 inch SAP shell	£165
01 November 1923	British Navy	2,400	6 inch common pointed shell with Ballistic Cap	£32,145
01 November 1923	British Navy	5,600	6 inch common pointed shell with Ballistic Cap	£60,425
22 December 1923	British Navy	16	16 inch APC shell improved design	£2,200
03 January 1924	British Navy	10	5.2 inch SAP representative shell	£47
21 January 1924	British Navy	100	15 inch APC representative shell	£4,550
24 January 1924	British Navy	12	15 inch SAPC shell	£1,554
15 March 1924	British Navy	180	5.2 inch SAP shell	£1,278
05 April 1924	British Navy	1,600	4.7 inch SAP shell	£9,131
30 April 1924	British Navy	16	8 inch APC shell	£373
16 June 1924	British Navy	30	15 inch SAPC representative shell	£1,425
17 June 1924	British Navy	42	6 inch APC representative shell	£504
18 July 1924	British Army	5,000	3 pound AP shell	£2,875
10 July 1924	British Army	8	9.2 inch AP Capped shell	£384
19 August 1924	British Navy	1,200	16 inch APC shell	£177,231
08 September 1924	British Navy	38	6 inch, 50 calibre shell	£453
10 September 1924	British Navy	600	6 inch common pointed shell with Ballistic cap	£7,134
20 October 1924	British Navy	164	8 inch APC representative shell	£2,369
21 November 1924	British Army	20,000	3 pound AP shell	£11,289
03 December 1924	British Army	2,000	4.7 inch SAP shell	£9,514
16 December 1924	British Navy	12	4.7 inch heavy SAP shell	£61
27 December 1924	British Navy	10	4.7 inch heavy SAP shell	£59
22 January 1925	British Navy	10	6 inch APC shell	£180
03 February 1925	British Navy	1,000	16 inch APC shell	£151,536
12 February 1925	British Navy	3,200	6 inch common pointed shell with Ballistic cap	£37,078
17 February 1925	British Navy	26	7.5 inch SAPC shell with Ballistic cap	£808
19 February 1925	British Navy	20	4 inch SAP representative shell	£109
20 March 1925	British Navy	23	6 inch APC representative shell	£13
21 March 1925	British Army	10	9.2 inch common pointed ballistic cap shell	£435
18 May 1925	British Navy	13	16 inch APC representative shell	£68
27 May 1925	British Army	1,000	60 pounder high explosive shell	£2,605
16 June 1925	British Navy	10	4.7 inch SAP representative shell	£41
24 June 1925	British Navy	12	4.7 inch SAP heavy shell	£72
29 June 1925	British Army	12	8 inch SAP shell	£405
29 June 1925	British Army	12	8 inch SAPC shell	£501
11 August 1925	British Army	500	3.7 inch Howitzer shell	£775
11 August 1925	British Army	500	4.5 inch Howitzer shell	£1,077
28 August 1925	British Navy	3,000	6 inch common pointed shell with Ballistic cap	£36,015
09 September 1925	British Navy	6	16 inch APC representative shell	£390
11 September 1925	British Navy	30	7.5 inch representative SAPC shell	£622
06 October 1925	British Navy	12	16 inch representative shell	£780
12 October 1925	British Navy	406	6 inch CPBC representative shell	£539

24 October 1925	British Army	6,432	4.7 inch Howz HE Shell	£10,047
28 October 1925	British Navy	100	16 inch APC representative shell	£5,929
09 November 1925	British Navy	20	4 inch SAP representative shell	£81
20 November 1925	British Navy	10	4.7 inch SAP shell for trials	£80
21 December 1925	British Navy	20	8 inch SAP shell of various designs	£771
28 December 1925	British Navy	14	7.5 inch SAPC and 7.5 inch SAP shell	£426
06 January 1926	British Navy	20	8 inch representative SAPC shell	£312
06 January 1926	British Navy	20	8 inch representative SAP shell	£334
01 January 1926	British Navy	2,800	4.7 inch heavy SAP shell	£18,717
03 March 1926	British Army	6	9.2 inch AP Capped shell	£288
12 January 1926	British Navy	40	8 inch representative SAP shell	£613
20 January 1926	British Navy	100	16 inch APC representative shell	£5,965
12 February 1926	British Navy	12	8 inch SAPC shell	£511
13 February 1926	British Navy	10	5.2 inch representative SAP shell	£63
10 March 1926	British Navy	1,060	4.7 inch SAP shell	£6,006
15 March 1926	British Navy	10	16 inch cast steel practice shot	£462
21 April 1926	British Navy	5	8 inch SAPC shell	
21 April 1926	British Navy	5	8 inch SAPC representative shell	£258
29 April 1926	British Navy	130	8 inch SAPC representative shell	£2,225
19 May 1926	British Navy	24	6 inch CPBC shell	£320
07 June 1926	British Army	5,000	3 pound AP shell	£2,628
10 June 1926	British Navy	3,000	4.7 inch heavy HE shell	£7,177
05 July 1926	British Navy	6,000	8 inch SAPC shell	£214,849
15 July 1926	British Navy	10	4 inch SAP shell weighted salt	£79
30 July 1926	British Navy	40	7.5 inch SAPC representative shell	£968
16 August 1926	British Navy	10	6 inch CPBC shell representative	£50
16 August 1926	British Navy	20	16 inch practice projectiles	£1,470
02 December 1926	British Army	50	9.2 inch representative APC shell	
02 December 1926	British Army	50	9.2 inch representative CPBC shell	£2,552
15 December 1926	British Navy	20	16 inch practice projectiles	£904
21 December 1926	British Navy	14	15 inch SAPC shell	£1,653
31 December 1926	British Navy	2,000	7.5 inch SAPC shell	£57,914
17 January 1927	British Navy	5,000	4 inch high explosive heavy shell	£7,500
21 January 1927	British Navy	40	6 inch CPC to various specifications	£610
10 February 1927	British Navy	2,400	8 inch SAPC shell	£85,456
29 March 1927	British Navy	180	16 inch APC representative shell	£10,597
29 March 1927	British Navy	10	4 inch SAP heavy shell	£66
13 April 1927	British Navy	12	7.5 inch SAPC shell	£405
28 May 1927	British Navy	2,000	4.7 inch heavy high explosive shell	£4,701
28 May 1927	British Navy	5,000	4 inch high explosive heavy shell	£7,415
23 August 1927	British Navy	2,000	6 inch CPBC shell	£23,180
26 July 1927	British Navy	40	16 inch APC representative shell	£2,250
11 August 1927	British Navy	100	16 inch APC representative shell	£5,625
20 September 1927	British Navy	40	15 inch target ship practice projectiles	£1,200
23 September 1927	British Navy	2,400	4.7 inch SAP heavy shell	£11,623
24 September 1927	British Navy	40	16 inch target ship practice projectiles	£1,340
07 October 1927	British Navy	4,800	8 inch SAPC shell	£165,963
15 November 1927	British Navy	5	16 inch practice projectiles	£335
26 November 1927	British Navy	100	16 inch APC representative shell	£5,625
07 December 1927	British Navy	1,600	7.5 inch SAPC shell	£46,033

03 January 1928	British Navy	4,400	4 inch SAP heavy shell	£19,091
10 February 1928	British Navy	120	16 inch APC representative shell	£6,750
18 April 1928	British Navy	12	16 inch practice projectiles	£739
17 May 1928	British Navy	250	16 inch APC representative shell	£14,062
17 May 1928	British Navy	400	4.7 inch SAP shell MK1	£1,960
17 May 1928	British Navy	2,000	4.7 inch SAP shell MK2	£10,098
19 May 1928	British Navy	4,600	4.7 inch HE shell	£10,876
19 May 1928	British Navy	11,000	4 inch HE shell	£16,320
02 June 1928	British Navy	400	4.7 inch heavy SAP shell	£1,971
13 June 1928	British Navy	3,200	8 inch SAPC shell	£109,388
25 June 1928	British Army	6	9.2 inch AP shell	£299
10 August 1928	British Navy	12	15 inch APC shell	£1,483
13 August 1928	British Army	24	9.2 inch APC representative shell	£480
13 August 1928	British Army	24	9.2 inch CPBC respresentative shell	£552
27 August 1928	British Army	40	9.2 inch heavy practice shot	£360
05 October 1928	British Navy	7,200	4.7 inch SAP heavy shell	£35,514
12 October 1928	British Navy	200	16 inch APC representative shell	£11,874
24 November 1928	British Navy	1,000	8 inch SAPC shell	£36,433
06 December 1928	British Navy	200	15 inch practice target ship projectiles	£6,650
03 January 1929	British Navy	100	7.5 inch target ship practice shell	£1,782
19 January 1929	British Navy	15	16 inch APC representative shell	£904
16 February 1929	British Navy	300	16 inch practice projectiles	£13,144
01 March 1929	British Navy	40	15 inch practice projectile target ship	£2,009
08 June 1929	British Navy	5,000	4 inch heavy HE shell	£7,540
24 July 1929	British Navy	12	8 inch SAPC shell	£253
02 August 1929	British Army	2	9.2 inch APC shell	£96
11 September 1929	British Navy	8,800	4.7 inch heavy SAP shell	£43,252
02 October 1929	British Army	3,009	4.5 inch HE Howitzer shell	£4,938
02 October 1929	British Army	503	4.5 inch smoke Howitzer shell	£1,062
23 October 1929	British Navy	100	15 inch APC shell	£13,247
04 November 1929	British Navy	1	15 inch SAPC shell	£125
16 November 1929	British Navy	11	6 inch CPBC shell (New Design)	£239
12 December 1929	British Navy	56,000	2 pounder high explosive shell	£12,624
12 December 1929	British Navy	9,000	2 pounder projectiles	£2,591
08 February 1930	British Army	5	9.2 inch APC shell	£243
17 April 1930	British Navy	80,000	2 pounder common nose fuze shell	£17,007
30 April 1930	British Navy	160	6 inch CPBC representative shell	£1,074
12 May 1930	British Navy	20,000	2 pounder HE shell	£4,507
24 May 1930	British Navy	900	4.7 inch Heavy HE shell	£2,125
27 May 1930	British Navy	200	16 inch practice projectiles	£8,600
29 May 1930	British Navy	50,000	2 pounder practice projectiles	£9,398
06 June 1930	British Navy	500	4.7 inch heavy practice projectiles	£1,496
04 July 1930	British Navy	5,000	2 pound tracer projectiles	£1,465
04 July 1930	British Navy	3,500	8 inch practice projectiles	£32,625
31 July 1930	British Navy	4,000	4.7 inch heavy SAP shell	£19,954
19 August 1930	British Army	3	9.2 inch APC projectiles for costal defence	£57
09 September 1930	British Navy	4,000	4 inch practice projectiles	£8,157
11 October 1930	British Navy	70	16 inch high explosive shell	£6,587

Source: Sheffield Archives, Hadfields Projectile Order Books Volume 3 to 5.

Section 2: Firth's Orders

Note: Firth's orders are recorded only by year and as British Government orders. No further details are available.

Order Date	Customer	Quantity	Description	Value
1920	British Government	2,400	7.5inch CPC	£43,200
1920	British Government	400	13.5inch APC	£36,000
1920	British Government	800	13.5inch APC	£72,000
1920	British Government	2	15inch APC Experimental	£250
1921	British Government	400	15inch APC	£50,000
1921	British Government	4	16inch APC Experimental	£600
1921	British Government	15	6inch AP Experimental	£225
1921	British Government	400	13.5inch APC	£36,000
1921	British Government	1,000	15inch APC	£125,000
1922	British Government	18	6inch AP Experimental	£270
1922	British Government	10	6inch AP Representative	£90
1922	British Government	400	15inch APC	£50,000
1922	British Government	12	4.7inch SAP	£84
1922	British Government	2	6inch APC	£30
1922	British Government	12	16inch APC Experimental	£1,800
1922	British Government	12	7.5inch APC Experimental	£360
1922	British Government	26	6inch AP Experimental	£390
1923	British Government	800	6inch CPBC	£9,600
1923	British Government	3,200	6inch CPBC	£36,000
1923	British Government	400	15inch APC	£50,000
1923	British Government	4,400	6inch CPBC	£47,300
1924	British Government	12	16inch APC Experimental	£1,800
1924	British Government	2,000	4.7inch SAP	£11,350
1924	British Government	16	8inch APC Experimental	£688
1924	British Government	40	7.5inch APC Experimental	£1,375
1924	British Government	2	6inch CP Experimental	£24
1924	British Government	800	16inch APC	£120,533
1924	British Government	4	7.5inch APC Experimental	£120
1924	British Government	400	6inch CPBC	£4,300
1925	British Government	600	16inch APC	£89,885
1925	British Government	1,600	6inch CPBC	£20,667
1925	British Government	32	7.5inch SAPC Experimental	£888
1925	British Government	12	4.7inch SAP Experimental	£84
1925	British Government	28	8inch SAPC Experimental	£1,077
1925	British Government	2,200	6inch CPBC	£26,336
1925	British Government	40	7.5inch APC Experimental	£1,370

1925	British Government	10	4.7inch SAP	£67
1925	British Government	48	8inch SAPC Experimental	£1,905
1926	British Government	1,800	4.7inch SAP	£10,057
1926	British Government	12	8inch SAPC Experimental	£512
1926	British Government	20	8inch SAPC Representative	£320
1926	British Government	3	50lbs Bombs	£117
1926	British Government	3	120lbs Bombs	£125
1926	British Government	3	250lbs Bombs	£153
1926	British Government	3	500lbs Bombs	£188
1926	British Government	24	6inch CPBC Experimental	£324
1926	British Government	3,200	8inch SAPC	£114,400
1926	British Government	400	8inch SAPC	£14,150
1926	British Government	10	4inch SAP Experimental	£80
1926	British Government	14	15inch SAPC	£1,806
1926	British Government	1,200	7.5inch SAPC	£34,650
1927	British Government	4	1500lbs Bombs	£394
1927	British Government	1,600	8inch SAPC	£56,600
1927	British Government	25	7.5inch APC	£856
1927	British Government	12	7.5inch SAPC	£412
1927	British Government	1,200	6inch CPBC	£13,400
1927	British Government	2,800	8inch SAPC	£95,620
1927	British Government	1,200	7.5inch SAPC	£34,200
1928	British Government	2,400	4inch SAP	£10,440
1928	British Government	6	450lbs Bombs	£382
1928	British Government	2,000	8inch SAPC	£68,125
1928	British Government	12	15inch APC	£1,449
1928	British Government	4,000	4.7inch SAP	£19,900
1928	British Government	600	8inch SAPC	£20,438
1929	British Government	12	8inch SAPC	£347
1929	British Government	5,200	4.7inch SAP	£25,740
1929	British Government	100	15inch APC	£12,700
1929	British Government	1	15inch SAPC	£129
1929	British Government	55	6inch CPBC	£456
1930	British Government	4	2000lbs Bombs	£454
1930	British Government	150	16inch Practice	£6,390
1930	British Government	2,000	8inch Practice	£18,400
1930	British Government	2,400	4.7inch SAP	£11,940

Source: Sheffield Archives, Firth-Brown Records

Appendix D: Brown's Monthly Armour Orders 1904-1924

	January	February	March	April	May	June	July	August	September	October	November	December
1904	£579	£90	£298,485	£0	£4,198	£0	£197,860	£24	£0	£43	£435	£86
1905	£571	£5,555	£3,400	£2,012	£0	£0	£2,725	£936	£184	£934	£5,737	£215
1906	£33,750	£117,892	£238,236	£235	£0	£7,606	£0	£0	£0	£99	£109	£368,618
1907	£230	£61	£75	£0	£3,779	£0	£1,800	£288	£1,972	£0	£32	£0
1908	£288,776	£0	£0	£545	£5,102	£400	£21,124	£720	£608	£0	£0	£3,180
1909	£146,603	£0	£1,601	£864	£1,700	£0	£169,900	£0	£1,535	£27,055	£792	£613
1910	£152,875	£800	£192,448	£132,504	£31,506	£274,350	£698	£7,659	£2,062	£746	£784	£10,500
1911	£80,394	£249,605	£32	£0	£0	£53,784	£47,886	£15,733	£88,990	£0	£0	£0
1912	£245,298	£0	£65,137	£0	£0	£150,435	£52,792	£74,296	£1,660	£504	£0	£71,016
1913	£43,424	£3,767	£102,241	£0	£517	£611,002	£0	£86,009	£6,309	£2,800	£204	£0
1914	£0	£0	£11,746	£0	£0	£287,576	£28,088	£2,563	£0	£3,094	£0	£64,986
1915	£0	£217,511	£13,971	£109,300	£0	£3,093	£1,296	£0	£0	£1,000	£51	£6,665
1916	£315	£4,212	£0	£880	£0	£0	£0	£0	£0	£0	£0	£0
1917	£4,455	£108,480	£0	£0	£0	£0	£49,187	£0	£5,764	£10,104	£10,104	£564
1918	£0	£0	£0	£0	£0	£0	£10,935	£0	£0	£7,950	£61,944	£0
1919	£0	£0	£14,825	£0	£5,350	£0	£0	£0	£0	£0	£0	£5,000
1920	£10,000	£0	£0	£0	£0	£86,273	£0	£0	£0	£0	£23,923	£0
1921	£0	£2,500	£0	£0	£0	£5,862	£0	£26,980	£0	£16,510	£0	£0
1922	£0	£0	£0	£0	£300	£0	£0	£3,534	£1,494	£0	£0	£565,135
1923	£0	£0	£47,626	£5,760	£0	£0	£0	£0	£0	£0	£0	£0
1924	£0	£0	£0	£0	£0	£0	£0	£67	£0	£0	£0	£0

Source: Sheffield Archives, X308/1/2/1/3/1 to 21, Brown's Managing Directors Reports 1905-1924

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